University of Alberta

Assessing the Air Quality and Human Exposure to Selected Volatile Organic Compounds in Fort McKay, Alberta

by

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ABSTRACT

In 1999-2000 Phase One of this study established a series of baseline levels of volatile organic compounds (VOCs) in the community of Fort McKay, AB. Phase Two was conducted between September to November 2006, and examined VOC levels following a series of oil sand facility expansions in the regional area. Passive monitors were placed at randomly selected locations within the community to assess indoor, outdoor, and personal exposure levels. The VOCs reported in this study included hexane, heptane, octane, nonane, decane and 3-methylhexane. The BTEX compounds are reported in another sudy. The primary objective of this study was to compare these levels to those obtained in the baseline study. In addition, the relationships between indoor, outdoor and personal exposure were examined.

It was determined that indoor concentrations of VOCs were greater than those detected outdoors ($P<0.0001$). Indoor-outdoor ratios supported that indoors sources would contribute more to personal exposure levels than outdoor sources. Levels of selected personal and indoor VOCs observed within the community of Fort McKay were found to have increased from the Baseline Study ($P<0.0001$). No observable change in outdoor levels was detected as values were below method detection limits. This information is intended to assist in understanding factors affecting human exposure in the community.

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LIST OF ABBREVIATIONS

AB	Alberta
AHW	Alberta Health and Wellness
ARC	Air exchange rate
Bpd	Barrels per day
BTEX	Benzene, Toluene, Ethylene, and Xylene
CAA	Clean Air Act
CASA	Clean Air Strategic Alliance
CEHEAP	Community Exposure and Health Effects Assessment Program
CLT	Central Limit Theorem
COV	Coefficient of Variation
CS_2	Carbon disulfide
EPA	Environmental Protection Agency
GC	Gas chromatograph
GerES	German Environmental Study
HEMP	Human Exposure Monitoring Program
HP	Hewlett-Packard
IPCS	International Programme on Chemical Safety
LOD	Limit of detection
MDL	Method detection limit
MS	Mass spectrometer
NAS	National Academy of Science
NO_2	Nitrogen dioxide
O_3	Ground level ozone
OVM	Organic Vapour Monitor
PEM	Personal Effects Monitor
$PM_{2.5}$	Particulate Matter 2.5
PVC	Polyvinyl Chloride
QA/QC	Quality assurance/ Quality control
RDS	Relative standard deviation
SAR	Sample analysis request
SBS	Sick building syndrome
SO_2	Sulphur dioxide
TEAM	Total Exposure Assessment Methodology
TWA	Time-weighted Average
US	United States
VOC	Volatile Organic Compound
WBEA	Wood Buffalo Environmental Association
WHO	World Health Organization

LIST OF SYMBOLS

α	Alpha
A	Cross sectional area of the diffusion area
C	Pollutant concentration
cm^2	Centimetres squared
°C	Degrees Celsius
D	Diffusion coefficient
h	Hour
Km/h	Kilometre per hour
L	Length of the diffusion path
m	Meter
m/s	Meter per second
mL	Millilitre
mm Hg	Millimetre mercury; a unit of pressure equal to 0.001316 atmosphere
min	Minute
n	Sample size
N	Paired samples
ng	Nanogram
$\mu g/m^3$	Microgram per meter cubed
µg/ml	Microgram per millilitre
µl	Micro-litre
r^2	Spearman rank order correlation coefficient
T_+	Wilcoxon signed rank test statistic
U^1	Mann- Whitney U-test statistic
U_i	Uptake rate
~	Approximately
=	Equal to
>	Greater than
<	Less than
%	Percent

CHAPTER 1.0: INTRODUCTION

1.1 Background Information

Though several studies have found that acute exposure to some air pollutants may have related health effects (Lebret et al. 1986, Wallace et al. 1986, Hartwell et al. 1992, Hoffman et al. 2000), there have been few studies that have examined long term, low dosage exposure. It is these types of monitoring programs that are needed to establish correlations between industrial emission on air quality, and ultimately human health in a population.

Intense oil sand development activity is occurring in Northern Alberta. Fort McKay, Alberta is a First Nations community located in the region, and within close proximity to several major oil sand industries that emit a variety of air pollutants. Concern over the impact of these industries on the air quality in the region, and the resulting health effects, led to the establishment of the Human Exposure Monitoring Program (HEMP) (Alberta Health and Wellness (AHW) 1997). HEMP is a joint initiative between the Wood Buffalo Environmental Association (WBEA) and the Northern Lights Regional Health Authority. In 1999 and 2000, Phase One of a study established a series of baseline assessments for volatile organic compounds (VOCs) in Fort McKay (Miyagawa and Kindzierski 2001). Since then, additional expansion and development of oil sands facilities in the region created a situation where potential impacts from this activity could be assessed.

This project comprised Phase Two of a monitoring program, following additional expansion and development of oil sands facilities in the region in 2002. A set of exposure

measurements that were similar to Phase One were made to assess potential impacts of increased industrial emissions to community air quality and human exposure in Fort McKay. By monitoring indoor, outdoor and personal exposure levels before, and after these series of expansions, a record of exposure was established. These results can offer an accurate picture of exposure of Fort McKay residents to VOCs.

The objectives of this study were to:

- Examine relationships between concentrations in personal, indoor, and outdoor air.
- Assess exposure in the population to selected VOCs.
- Compare selected VOCs with baseline levels.
- Increase understanding of factors affecting human exposure.

1.2 Description of Study Area

1.2.1 Community Description

The community of Fort McKay is a First Nations Reserve located in Northern Alberta. It is situated approximately 60km north of Fort McMurray, and 450km northeast of Edmonton (Figure 1). It is home to approximately 521 residents, residing in a total of 95 housing units (Statistics Canada 2007). The majority of residences are single family houses, though some multi-family units and mobile homes exist in the community.

1.2.2 Industrial Activity

Oil sand industrial activity is occurring in Northern Alberta. There are currently three main industries present in region that are involved in a series of oil sands mining,

bitumen extraction, and synthetic crude oil production. Suncor Inc. (Suncor), Syncrude Canada Ltd. (Syncrude), and more recently Shell Canada Ltd. (Shell), are the leading producers in the region. Raw bitumen production in 2006 was targeted around 195,000 barrels per day (bpd) at the Suncor Mine, 350,000 bpd at the Syncrude Mine, and 155,000 bpd at the Shell Mine (Suncor 2007, Shell 2006, Syncrude 2006). Future projections estimate total production in the region to be greater then 1,000,000 bpd by 2020 (Suncor 2007, Shell 2006, Syncrude 2006).

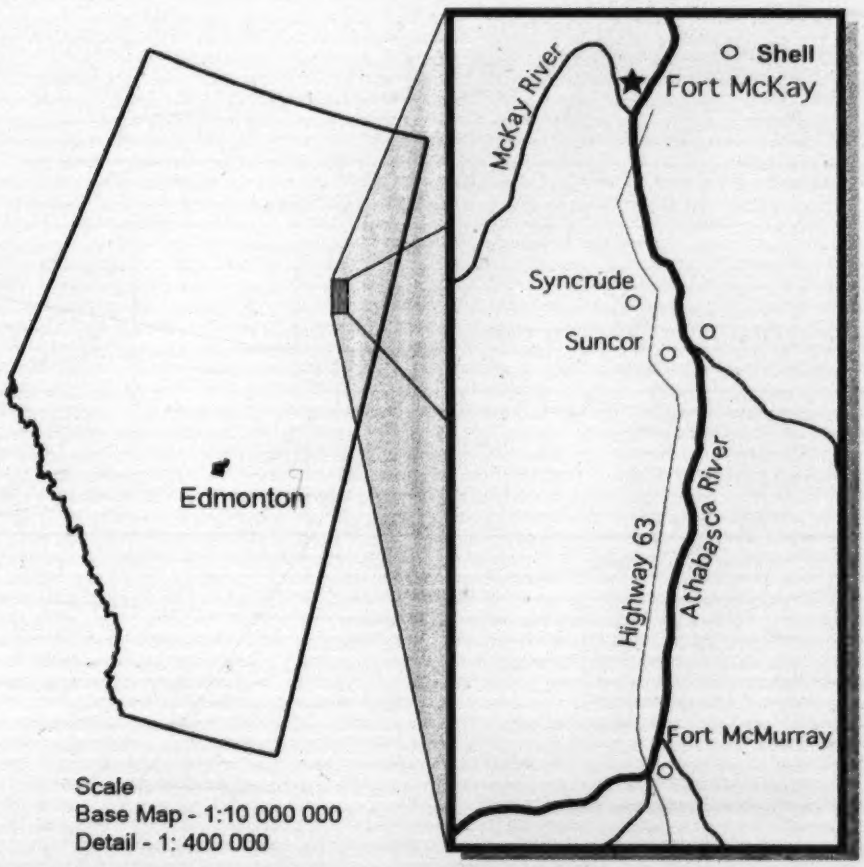


Figure 1. Map of approximate location of the community of Fort McKay in relation to Fort McMurray, and major oil sand developments, Shell, Syncrude, and Suncor (Adapted from Miyagawa and Kindzierski 2001).

1.3 Study Hypotheses

This study posed three hypotheses; one main hypothesis, with two secondary hypotheses. The main hypothesis tested:

Hypothesis 1: Increased oil sands activity in the region had no significant influence on the indoor, outdoor and personal levels of VOCs in the community of Fort McKay. This was based upon the initial findings of the baseline study that determined levels of VOCs to be higher indoors than outdoors (Miyagawa and Kindzierski 2001). Ott and Roberts (1998) also concluded that large outdoor point sources in the US which were suspect to being a source for human exposure, played less of a role than personal activities and indoor sources.

In addition, two secondary hypotheses were tested:

Hypothesis 2: Concentrations of VOCs in indoor air are significantly greater than those in outdoor air. Previous exposure studies have found that indoor concentrations are typically greater than those found outdoors due to the abundance of VOC sources indoor (Pellizzari et al.1986).

Hypothesis 3: Personal levels of VOCs are not significantly greater than, and are closely related to indoor VOC levels. Though personal activities have been found to influence personal exposure (Ott and Roberts 1998), the majority of Canadians spend an overwhelming 89% of their time indoors (Leech et al. 1997). This time has been shown to have a greater impact on exposure trends.

1.4 Methodology Overview

A volunteer recruitment process similar to that established in the baseline assessment was used in this study (Miyagawa and Kindzierski 2001). An information letter was distributed to the homes in the community prior to the commencement of the study, to inform the residents of the purpose and objectives of the study. To maintain statistical comparison, a stratified probability sampling design was then used to identify potential participants in the community. The population was stratified according to housing type (house or mobile home) to account for variation in construction materials. A list of randomly generated numbers was used to select homes of potential participants. The field staff then initiated a door-to door campaign to recruit volunteers, until the targeted 35 participants were attained.

The 3M ® Organic Vapour Monitor 3500 (OVM), a passive sampler, was used to maintain consistency with the baseline study (Miyagawa and Kindzierski 2001). Monitors were deployed to collect indoor, outdoor and personal concentrations over a continuous seven-day (168 hour) period. Both spatial and temporal considerations were made to reduce the amount of bias and/or error in the sampling. Monitoring was conducted for a seven day period to encompass any temporal changes in exposure due to personal activity over the course of weekday and weekend. The length of this sampling period was sufficient to readily collect low concentration air pollutants (WBEA 2006a). Exposed monitors were shipped to the Centre for Toxicology in Calgary, Alberta for analysis. A series of 35 blanks were also deployed to test precision of the monitors.

Participants were also asked to maintain a time activity diary for the duration of sampling. This information was not used in analysis of the results.

CHAPTER 2.0: LITERATURE REVIEW

2.1 Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are a diverse group of compounds that contain carbon. Aromatic hydrocarbons, halogenated hydrocarbons, aldehydes, ketones, aliphatic hydrocarbons, alcohols, ethers and esters are all included in this group (Brooks and Davis 1992). They exist in the gaseous state over the normal range of air temperature and pressure, and have boiling points between 50°C to approximately 260°C (Wolkoff and Nielsen 2001). VOCs are of interest since in the presence of sunlight they can react with the oxides of nitrogen to form ozone and photochemical smog (CASA 2007). Over 1000 different VOCs have been identified, with over 300 detected in indoor air (Otson and Fellin 1992). This makes VOCs one of the most diverse groups of indoor air pollutants.

Over the past few decades, there has been an increase in concern over the toxicity of VOCs to humans, animals, and vegetation. The United States (US) 1990 Clean Air Act (CAA) Amendments established Federal and State programs to regulate the emissions of a large number of air pollutants that can cause cancer, reproductive harm, other serious illnesses as well as environmental damage (WHO 1995). Studies have found that several organic compounds found in the environment have been found to have adverse effects on human health even at low concentrations (Oury et al. 2006).

Attention to several standardized VOCs has been initiated through several large scale studies such as the US Environmental Protection Agency (EPA) Total Exposure Assessment Methodology (TEAM) study (Wallace et al. 1986) and the German

Environmental Study (GerEs) (Hoffmann et al. 2000). The main concern surrounding indoor VOC pollution is the lack of existing legal thresholds for the majority of components. Published data are available for only a fraction of the VOCs that are known or suspected to occur in indoor air. The uncharacterized VOCs likely include a number of compounds important with respect to human health, sensory irritation and odour that have not been measured because they are inadequately collected or analyzed by conventional methods (Wolkoff and Nielsen 2001, Wolkoff et al. 1997).

However, as detection capabilities improve and complaint rates continue to rise, monitoring of other compounds has been suggested. The detection of several additional VOCs over the last decade can be attributed to the development of new sampling/analytical techniques, and the introduction of new building products and solvents (Wolkoff and Nielsen 2001, Wolkoff et al. 1997). Expanding beyond the standard VOC window as defined by the World Health Organization (WHO) (WHO 1995) will assist in determining the effects of other compounds on human exposure.

2.1.1 VOCs Selected for Study

Twelve major VOCs tested in the baseline study were monitored to determine any changes in concentration levels. This report will focus on the straight chain aliphatic compounds (hexane, heptane, octane, nonane, and decane), and 3-methylhexane. All these compounds are constituents of gasoline. A companion thesis by Hoeksema (2007) presented results on benzene, toluene, ethylene, and xylene (BTEX).

2.1.1.1 Hexane

Like most VOCs, hexane occurs naturally and can be synthetically generated. Hexane is a minor constituent of crude oil and natural gas, and is used in the industrial extraction process (AHW 2006). When in its liquid state, it is colourless and has a mild gasoline-like odour (IPCS 2006). Hexane quickly evaporates into air, and predominantly exists in the vapour state (IPCS 2006). It is insoluble in water. Hexane is also used as a cleaning agent for textiles, furniture and leather (AHW 2007).

2.1.1.2 Heptane

Heptane is a colourless liquid, and an important constituent of gasoline and aviation fuel. It is also a major component of several petroleum solvents such as petroleum naphtha and rubber solvent. Heptane is commonly used as a solvent in a variety of glues, varnishes, cements and inks that dominate the indoor environment (AHW 2007).

2.1.1.3 Octane

Octane is one of the most familiar components of gasoline. However its use in eye makeup, furniture polishes, and household cleaners is less known (AHW 2007). All types of paint and paint thinners, wood office furniture, photocopying machines and work surfaces (modular systems) contain some concentration of octane (AHW 2007).

2.1.1.4 Nonane

Nonane is another colourless component of gasoline and the related petroleum solvents. Its used can also be noted in paraffin products, the paper processing and rubber industries, and in the synthesis of biodegradable detergents (AHW 2007).

2.1.1.5 Decane

Like most of the hydrocarbons, decane has a noticeable gasoline odour. Its vapour is heavier than air, and may spread long distances and accumulate in low-lying areas (AHW 2007). It is a component of gasoline, jet fuel, and kerosene and is used in the rubber and paper industries (AHW 2007).

2.1.1.3 3-Methylhexane

3-Methylhexane is an isomer of another common VOC, heptane. Two common isomers of methylhexane exist; 2-methylhexane, and 3-methylhexane, indicating the carbon group on which the additional carbon group is attached. Commonly found in paint and other solvents, 3-methylhexane is a colourless liquid with a slight gasoline-like odour (AHW 2006).

2.1.2 Sources of VOCs

VOCs have natural and anthropogenic sources, and vary between indoor and outdoor sources. Ott and Roberts (1998) concluded that large outdoor point sources in the US which were suspect to being the source for human exposure, played less of a role than personal activities and indoor sources.

Biogenic emissions from plant foliage accounts for an estimated two thirds of total global VOC emissions (Muller 1992). Most anthropogenic sources arise from automobile fuel combustion and industrial emissions. Vehicle emissions are the predominant source of VOCs in the ambient environment, accountable for over 33% of the total level (Scheff and Wadden 1993). Wallace et al. (1986) found that industry is responsible for less than

25% of VOC concentrations. It was estimated that 800kt annually are emitted from industrial and transportation processes in Canada (National Emission Inventory and Projection Task Group 1995).

VOC sources vary between indoors and outdoors. When conducting exposure studies, it is necessary to examine the influence of outdoor versus indoor sources (WHO 1995). Though outdoor sources can contribute a small percentage of indoor VOC levels, the indoor environment typically has higher levels of VOCs than outdoors (Miyagawa and Kindzierski 2001, Otson and Fellin 1992, Wallace et al. 1986). This relationship can be demonstrated by looking at the ratio of indoor to outdoor concentrations. Major indoor sources include consumer products (solvents, cleaners, air fresheners, moth balls, etc.) and personal activities (smoking tobacco products, wearing dry cleaned clothes, etc.). Building related products (latex paints, polyurethane floor finishes, synthetic fabrics, floor wax and wax strippers, floor and carpet adhesives, particle board, fluorescent lighting etc) can also contribute to indoor VOC levels.

It has been found that personal exposure correlates with indoor, not outdoor VOC levels; and indoor sources are responsible for most VOC exposure (Wallace 1991). Sack et al. (1992) compiled a survey of household products containing VOCs. Out of 1043 products tested 9.7% were found to contain hexane, out of 470 tested products 14% contained octane, and nonane was found in none of the 66 products (Sack et al. 1992). The sources of their findings are summarized in Table 1. However, it should be noted that the GC/MS analyses were not extended much beyond the retention time of the latest-eluting

chlorinated solvent, tetrachloroethylene (Sack et al. 1992). Thus, analytes that elute after tetrachloroethylene would not have been detected. The predominant source of 3-methylhexane is paint and other types of solvents (AHW 2006).

Table 1. Summary of potential sources of hexane, octane and nonane in household products

Source (Conc.*)	Hexane	Octane	Nonane
Automotive products	7.4	0.2	0.0
Household cleaners/polishes	2.0	0.6	0.0
Paint related products	6.3	1.2	0.0
Fabric and leather treatments	2.4	2.1	0.0
Cleaners for electronic equipment	0.1	0.0	0.0
Oils, greases, and lubricants	12.6	0.1	0.0
Adhesive related products	26.5	3.9	0.0
Miscellaneous products	2.0	0.0	0.0

Adapted from Sack et al. (1992).
* Average concentration (%w/w) of chemical in product containing chemical.

Previous studies have also found elevated levels of VOCs in the homes of smokers (Gonzalez-Flesca et al. 2000, Otson and Fellin 1992). Elevated personal exposure to benzene, toluene, styrene, m,p-xylene, and o-xylene have been detected in participants exposed to environmental tobacco smoke (Edwards et al. 2001a).

2.1.2 Environmental Influences

Environmental conditions including temperature, relative humidity, and ventilation rate have an influence on the emission rate and fate of VOCs (Otson and Fellin 1992). Variations in boundary conditions such as nutrition, ethnicity, climatic or geographic conditions, and type of pollutant mixture have also been found to impact exposure (WHO 1995). When conducting sampling it is important to assure that exposure is assessed over representative seasonal periods to attain the most accurate assessment. Most chemicals

display a variation over seasonal cycles, due to changing temperatures. The results of Schlink et al. (2004) and Schneider et al. (2001) provide evidence to support seasonal variation in VOCs.

In the Phase One study, indoor VOC levels were higher in the winter months than in the summer months (Miyagawa and Kindzierski 2001), which was similar to other studies (Schlink et al. 2004, Schneider et al. 2001). Decreased building ventilation rates in the winter have been suggested as the predominant potential source for these higher indoor VOC levels (Seifert and Abraham 1989). Dispersion of indoor VOCs is inhibited by low ventilation rates. Seasonal fluxes in indoor temperature and humidity have also been suggested as potential influences that may impact the intensity of indoor sources (Schlink et al. 2004).

2.1.3 Health Effects of VOCs

Indoor air pollution is one of the greatest threats to public health (Wallace 1991). Due to the vast numbers of VOCs, the result of exposure may vary from slight discomfort to serious health effects. Health effects of VOCs depend upon (Brooks and Davis 1992):

- toxicity of VOCs;
- route of exposure;
- actual dose of the VOC received from the environment;
- individual susceptibility to the VOC; and
- VOCs reactivity with other chemicals.

Thus obtaining an accurate analysis of exposure is vital in establishing, or predicting potential health risks. A wide variety of syndromes ranging from respiratory irritation and

infection to headaches, nausea and mental fatigue, have been classed together into a group referred to as "sick building syndrome" (SBS) (Molhave et al. 1986). This syndrome was classed after several studies established a correlation between time spent indoors in buildings, and resulting symptoms. High levels of VOCs in new and renovated buildings for a period of 6 months or so after completion has lead to speculation that SBS is an effect of VOC exposure (Wallace 2001). Some VOCs have also been found to attribute to smog formation, which can have implications on respiratory function and health.

2.2 Exposure Assessment

Exposure is generally defined as the contact of a pollutant with a susceptible surface of the human body. The National Academy of Science (NAS) (1991) defines contaminant exposure as "an event that occurs when there is contact at a boundary between human and the environment with a contaminant of a specific concentration for an interval of time". Assessing exposure is a complex process. Often establishing connections between a source and an effect can be difficult due to the multiple interactions and dynamics of all the parameters involved. General exposure can be determined indirectly through the mathematical expression (NAS 1991):

$$E = \int_{t2}^{t1} C(t)dt \qquad \text{Equation 1}$$

where C(t) represents the concentration over a time interval t_1 to t_2.

However, exposure to airborne pollutants occurs on a continual basis, thus it is important that all potential sources are integrated into exposure calculations. Exposure can also be long term or short term, and can be classed as occupational or environmental. Exposure

arising from predetermined amounts of time spent in confined spaces is defined as occupational exposure, whereas exposure occurring in several sites, outdoors, at home, in-transit, in other environments (theatres, sport arenas, restaurants etc.) over varying periods of time can be classed as environmental exposure (Moschandreas and Saksena 2002). Duan (1982) proposed that an individual's exposure can be determined by the equation:

$$E = \Sigma C_k t_k \qquad \text{Equation 2}$$

where C_k is the concentration of the pollutant in the k^{th} microenvironment, and t_k is the time spent in this microenvironment.

The term microenvironment describes the different locations (and different pollution concentrations) a test subject may pass through in the course of their day (Duan 1982). It is assumed that the air volume in these microenvironments has homogeneous pollution concentration levels (Moschandreas and Saksena 2002).

Typical routes of exposure include oral ingestion, adsorption through the epidermis, and inhalation. Humans have approximately 1-2 square meters of skin surface area, compared to 50 to 70 square meters of surface area within the respiratory system (EnHealth 2002). This makes inhalation the largest route of exposure for pollutants like VOCs. The US Environmental Protection Agency (EPA) Total Exposure Assessment Methodology (TEAM) study determined that inhalation accounts for 99% of exposure to VOCs due to their existence in the volatile state (Wallace et al. 1986). Thus it is customary to refer to

exposure of airborne pollutants as inhalation exposure (Moschandreas and Saksena 2002).

It has been estimated that the average adult Canadian spend upwards of 88.6% of their time indoors, 66% of this in their homes, and only 6.1% of their time outdoors (Leech et al. 1997). Children and seniors more commonly spend an increased amount of time indoors at home, elevating this level up to 90% (Leech et al. 1997). Indoor concentrations of several pollutants may be much higher than outdoor concentrations (Repace 1982). Of all environmental problems, indoor air pollution poses one of the greatest threats to public health (Wallace 1991). Thus, accounting for indoor air quality is an important aspect of exposure assessments.

Enhanced exposure information can be obtained through direct and indirect means (WHO 1995).

2.2.1 Direct Assessment

Direct assessment involves the measurement of the concentration of pollutants to which the monitor is exposed. There are two methods of direct sampling: active and passive. Active sampling consists of pumping a known volume of air over a collection medium or sensor. This requires a power source, making the device larger and bulky. The second method is known as passive or diffusive sampling (Harper and Purnell 1987). Passive sampling uses diffusion across an air gap to drive mass transfer of pollutants onto a collection medium (Zabiegala et al. 2005). These passive samplers are typically smaller

and allow for easy measurement of personal inhalation exposure. Analyte uptake in passive sampling is subjected to several limitations introduced by the effects of environmental conditions (i.e. temperature, air movement, and relative humidity) on the monitor (Gorecki and Namiesnik 2002).

Under real conditions, results of passive sampling and active sampling have shown close agreement (within ± 15%) (Cruz et al. 2004). A summary comparing the advantages and disadvantages between active and passive samplers is presented below in Table 2 (Krupa and Legge 2000).

Table 2. Summary of characteristics of passive and active monitors for quantifying air pollutant concentrations*

	Feature	Passive	Active
1	Complexity of field deployment	Low (+)	High (-)
2	Construction/ deployment cost	Low (+)	High (-)
3	Field labour requirement	Low (+)	High (-)
4	Field maintenance costs	Low (+)	High (-)
5	Laboratory analysis costs	Moderate to high (-)	None to moderate (+/-)
6	Time resolution of pollutant levels	Low (-)	High (+)
7	Electricity requirement for field deployment	None (+)	Needed (-)
8	Meteorology interference	Can be high (-)	Low (+)
9	Minimum detection limit (in fine-time resolution)	Relatively high (-)	Relatively low (+)
10	Regional (spatial) scale usage cost	Low (+)	High (-)
11	Detection of short term (e.g. 1 or 2h) episodes and regulatory non-compliance, where appropriate)	Low (-)	High (+)

*Adapted from Krupa and Legge (2000); (+) indicates advantage, (-) indicates disadvantage

2.2.1.1 Theory of Passive Sampling

The theory behind passive sampling has been covered in depth in several publications (Partyka et al. 2007, Oury et al. 2006, Miyagawa and Kindzierski 2001, Brown 2000, Kindzierski, Probert and Bryne-Lewis 2000, Krupa and Legge 2000, Harper and Purnell 1987).

The diffusion occurring in passive samplers is represented by Fick's First Law of Diffusion (Harper and Purnell 1987):

$$J = -D \times \left[\frac{dc}{dx}\right] \qquad \text{Equation 3}$$

where J is the diffusion flux (moles/cm^2/s), D is the diffusion coefficient (cm^2/s), dc is the approximation of environmental concentration minus interface concentration (moles/ cm^3), and dx is the approximate length of the diffusion path (cm). The negative symbol indicates that the unidirectional flow of mass transport is from the higher concentration to the lower concentration. By applying the principles of Fick's Law to a passive monitor (Figure 2), it is possible to calculate the mass of analyte retained on the collection medium (Partyka et al. 2007):

$$M = \left[\frac{D \times A}{L}\right] C_o\, t \qquad \text{Equation 4}$$

where M= mass of analyte retained (μg), D is the diffusion coefficient (cm^2/s), A is the cross sectional area of the diffusion surface (cm^2), and L is the length of the diffusion path (cm), C_o is the concentration in the ambient air (μg/cm^3), C is the concentration at the adsorbent surface (μg/cm^3), and t is the sampling time.

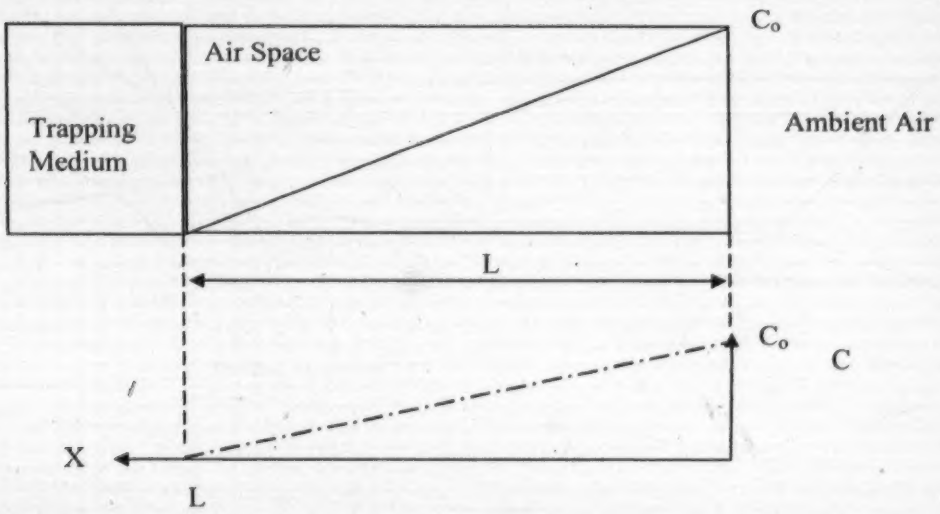


Figure 2. Schematics of a passive monitor derived from Fick's Law. Adapted from (Partyka et al. 2007)

The rate of analyte uptake onto the collection medium can then be determined by (Krupka and Legge 2000):

$$U_i = \frac{D \times A}{L} \qquad \text{Equation 5}$$

where U_i is the Uptake rate (cm^3/s).

The concentration of analytes in the air can then be calculated by:

$$C = \frac{m}{Ui \times t} \qquad \text{Equation 6}$$

where C is the pollutant concentration ($\mu g/cm^3$), m represents mass uptake which is the measured mass of the analyte, and t is the sampling time (s).

2.2.1.2 Personal Exposure Monitoring

Direct assessment is typically accomplished through the use of a personal exposure monitor (PEM). PEMs are often passive samplers, and are the preferred method due to their small size and easy use. PEMs typically have an alligator clip, or some other attachment device that allows for positioning within the personal breathing zone of the participant. Use of the same instrument to conduct all monitoring will provide results in relative proportions, thus eliminating any bias and allowing for direct comparisons to be made (Wallace 1991).

2.2.2 Indirect Assessment

The link between contaminant presence and contact with humans is complex and is largely determined by patterns of human behaviour (Samet and Lambert 1991). Since personal activity can account for increased exposure rates (Wallace 1991), indirect monitoring can be useful in establishing a model to account for exposure in microenvironments. Indirect assessment combines microenvironmental pollution concentrations weighted with time activity data to determine exposure rates. When concentration measurements are unavailable, the indirect method uses models to estimate pollutant concentrations, and employs these values as if they were measurements (Moschandreas and Saksena 2002). A combination of questionnaires and time activity logs are typically used to gain a better understanding of exposure due to human activity. Leaderer et al. (1986) describes a nested assessment method in which questionnaires and direct monitoring data are combined to provide a more accurate exposure assessment.

2.3 Personal Exposure Studies

Personal exposure studies to air pollution indoors and in the workplace were initially introduced through two large population based studies, the US TEAM study (Wallace et. al. 1987) and the European EXPOLIS study (Jantunen et. al. 1998). In 1979, the USEPA initiated the TEAM strategy to assess human exposure to airborne pollutants (Wallace et. al. 1987). The TEAM study (1980-1984) was the first and largest study undertaken to measure personal exposure to multiple pollutants (Ott et al. 1986). This study emphasized the necessity of measuring individual exposure to the targeted pollutants. The TEAM approach embodies four fundamental characteristics (Wallace et al. 1986):

1. direct measurement of all routes of exposure (breathing, ingestion, and skin contact);
2. direct measurement of biomarkers;
3. daily logs of a participant's activities; and
4. a representative probability sample.

Today, this model has been adapted by the World Health Organization (WHO) along with several other countries to assist in assessing exposure issues, and addressing human and environmental health concerns (AHW 2000c). Based upon the methodologies and protocols from the TEAM study, the Community Exposure and Health Effects Assessment Program (CEHEAP) was formed to collect information on airborne contaminants and health concerns across the province of Alberta (AHW 2006). The focus of this program is on airborne contaminants, and what an individual has inhaled throughout their normal activities. In the late 1990s an initial community exposure study was undertaken in Fort McMurray, AB. This pilot study is known as the Alberta Oil

Sands Community Exposure and Health Effects Assessment Program (AOSCEHEAP), and has been the baseline referral for methods and protocols for Alberta Health and Wellness (AHW 2007).

This model has been further developed into the Community Exposure and Health Effects Assessment Program (CEHEAP). To date, it has been implemented in several communities including Fort McMurray, Grand Prairie, Fort Saskatchewan and the Wabamum area. It is part of an ongoing effort by public health officials in Alberta to collect information on airborne contaminants and health concerns across the province. The scientific methodologies and protocols used in the program have been developed over many years, and have proven their effectiveness in previous assessment programs (AHW 2006).

CHAPTER 3.0: SAMPLE SELECTION PROCEDURE

3.1 Sampling Design

3.1.1 Probability Sampling

Sampling design refers to the layout and placement of samples at a site. The objective of a study will often determine which sampling design should be utilized. When data are used for risk and exposure assessment, unbiased sampling designs are often desired (Mattuck et al. 2005). Unbiased designs are probability based, meaning each unit has an equal chance of being selected and included in the data set (USEPA 2002). This sampling method provides a reliable estimate of variability, and allows statistical inferences to be drawn for the data set (USEPA 2002). Probability sampling is the only statistically viable method that is widely accepted for making inferences in exposure studies (Ott et al. 1986). This method also allows for direct comparison of collected data to that of other studies in the community.

A probability sampling method was designed by Cheperdak and Hoeksema (2006). It was used to randomly select sampling sites from which volunteers were recruited from within the community of Fort McKay, AB (Figure 1). Probability sampling has previously shown efficiency in selecting volunteers in small communities (AHW 2006, Kindzierski and Ranganathan 2006, Miyagawa and Kindzierski 2001, Kindzierski et al. 2000).

3.1.2 Stratification

Stratified sampling divides the area into uniform sections from which a representative sample can be taken. It assures that geographic representation is attained for the sampling

area. Several exposure studies have implemented a stratified sampling design (Miyagawa and Kindzierski 2001, Wallace 1987, Pellizzari et al. 1986). A single stage stratification method was developed and implemented in the study to randomly select dwellings that would be representative of the community of Fort McKay. Two strata were established based upon housing type: house or mobile home. Construction material, building age, and air ventilation have been identified as potential sources of variance between the two housing forms (Wolkoff and Nielsen 2001, Pellizzari et al. 1986). Otson and Meek (1995) found that mobile homes had the lowest concentrations for most VOCs.

3.2 Sample Selection

3.2.1 Target Population

All occupied, single family housing units in the community of Fort McKay were included in the target population. Volunteers were required to be over the age of 18. Smokers were not excluded from participation in the study.

3.2.2 Sampling Frame

A housing map for the community was obtained from the Fort McKay Industrial Relations Corporation (Appendix A). Due to a recent increase in new housing, field staff verified the accuracy and completeness of the map prior to usage. The location of single family homes and mobile homes was also noted. The map was then used to construct a housing list. Since two forms of housing units existed, two separate sampling frames were created to represent each form. The House list consisted of 137 units, and the Mobile Home list consisted of 19 units.

3.2.3 Sample Size and Strata

Determining the required sample size for an experiment is typically derived from the normal distribution. The Central Limit Theorem (CLT) is the basis for the assumption of normality in many statistical tests. It states that as sample size increases, the means of samples drawn from a population with any shape of distribution will approach the normal distribution (Mac Berthouex and Brown 2002). In other words, the distribution of a sample should approach normal distribution as the sample size increases. The CLT also assures that random errors tend to be distributed according to a standard normal distribution. This means that with large sample sizes (n>30), the assumption of a normal distribution is unnecessary, and the central limit theorem can be applied (Stuart 1984).

A set of 35 residential units was selected to participate in the study, which should ensure that a minimum of 30 samples were collected. Based upon the number of housing and mobile home units, and an overall sampling fraction of 0.224, it was determined that 31 houses and 4 mobile homes were needed to gain an accurate representation of the community. A summary of the community housing, and sampling fraction is presented in Table 3.

Table 3. Housing Unit Sampling Fractions

Housing Unit	# of Units	Sample Size Target	Sampling Fraction
Houses	137	31	0.226
Mobile Homes	19	4	0.211
Total	156	35	0.224

3.2.4 Random Selection Procedures

Starting at the south end of the community, a number and identifier were assigned to each house (H_1-H_n), and each mobile home (M_1-M_m). The houses were numbered from H_1 to H_{176}, and the mobile homes from M_1 to M_{19}. Selection procedures were generated independently for each housing form (Cheperdak and Hoeksema 2006).

In Excel®, a list of random numbers was generated to select housing units. Starting at the top of the list, when numbers 1 to 176 were identified, the house was place on the selected list. Numbers which repeated were removed from the list, as were any numbers greater than 176. This process continued until the 35 houses had been selected. The same process was repeated for the mobile homes, but discarded numbers over 19. The initial list for mobile homes consisted of 10 units.

3.3 Volunteer Recruitment

3.3.1 Recruitment Procedures

Prior to recruitment, an informational letter was delivered to each resident in the community. This letter indicated that a study would be taking place in their community, and that they may be asked to participate. A copy of this letter can be found in Appendix B. A door-to door campaign was then initiated to recruit volunteers.

Homes that had been randomly selected were visited by the field staff and project coordinator. A further explanation of the study was provided, and the resident was asked to be a participant. If the response was "yes", an information letter regarding the study

was given to the participant (Appendix C), and a set up appointment was scheduled. If the response was "no", the person was thanked for their time, and the location was noted as declining from participation in the study. In situations where there was no response, field staff would return to the location three times, or until a response was received. If no response was received upon the third visit, the location was marked as declined, or not at home. This process was repeated until the desired number of participants, 35, was attained.

3.3.2 Response Rates

Overall, the response rate from the community of Fort McKay was fairly low, at 37% participation. This rate was down slightly from the 51% response from the fall sampling session in the baseline assessment (Miyagawa and Kindzierski 2001). Low response rates are typical of personal exposure monitoring studies due to the unusually high respondent burden (Wallace et al. 1986). The target sample size for houses and mobile homes was 31 and 4 respectively. A summary of the community response rates are presented in Table 4.

Table 4. Community Response Rates

	Houses	Mobile Homes	Overall
Total households approached	76	19	95
Consent received	31	4	35
Declined/ Not at home	45	15	60
Completed	31	4	35
Response rate	**41%**	**21%**	**37%**

CHAPTER 4.0: SAMPLE COLLECTION

4.1 VOC Measurements

4.1.1 OVM 3500 Monitor

To ensure comparable results to the Baseline Study (Miyagawa and Kindzierski 2001), the 3M® Organic Vapour Monitor 3500 (OVM 3500) was used to conduct passive sampling in each location. This monitor (sampling badge) is relatively small and non-encumbering to the user. The OVM 3500 has typically been used to measure exposure to organic pollutants in industrial settings (3M 1996).

Several studies have tested the application of these monitors in a variety of settings and established advantages for using passive samplers to measure levels of VOCs indoors and outdoors (AHW 2006, Schlink et al. 2004, Miyagawa and Kindzierski 2001, Kindzierski et al. 2000, Hoffmann et al. 2000, Begerow et al. 1999, Otson et al. 1994). Use of the same instrument to conduct all monitoring will provide results in relative proportions, thus eliminating any bias and allowing direct comparison (Wallace 1991). The OVM 3500 has also been found effective in measuring low concentrations over a long exposure time (Oury et al. 2006).

The OVM 3500 is composed of an orange plastic case covered by a permeable Teflon membrane, retained by a plastic ring (Figure 3). Underneath, a plastic spacer separates the membrane from the activated charcoal sorbent pad. The diffusive cross sectional area of the monitor is $\cong 7.07\ cm^2$, and the diffusion distance length is $\cong$ 1cm (Bergerow et al. 1999). Each monitor had a metal alligator clip, which allows for easy affixing to the lapel

of the volunteer's clothing, or to the monitoring lanyard. Each of the badges was shipped individually in a vacuum-sealed aluminium can, with a secondary plastic snap lid. In addition to the badge, a plastic elution or closure cap with two sealable ports was included in each can.

Figure 3. The 3M® Organic Vapor Monitor 3500 (taken from Miyagawa and Kindzierski 2001)

4.2 Monitor Stands and Placement

Three sample measurements were taken at each location; personal, indoor and outdoor. The personal monitors were worn by one volunteer per residential unit for the duration of the testing period.

Prior to selecting a position for the placement of the indoor and outdoor monitors, a sketch of the unit's floor plan was made by one of the field staff (Appendix D). Indoor monitors were attached to a rope on a stand composed of ¾ inch polyvinyl chloride (PVC) piping, at a height of 1.2m (Figure 4) by the other field staff member. An indoor stand was then placed in the room in which the participant and residents spent the most

time. General guidelines for the positioning of monitor stands were developed based on manufacturing suggestions (3M 1999) and from previous experience from other studies (Cheperdak and Hoeksema 2006, Miyagawa and Kindzierski 2001, AHW 2000a, Byrne 2000). Ideally, these guidelines would assist in situating the monitors in a location with adequate airflow and minimal interference from potential contamination sources (i.e. windows and doors, vents, etc.). These placement procedures should assist in providing representative samples.

In some situations where there were small children or pets in the residence, the indoor monitors were sometimes placed on a lanyard and positioned in a discrete area that would not be accessible to the children or pets. In these cases, an effort was made to keep the sampling height at 1.2m, and was noted on the floor plan.

Outdoor monitors were secured to a stationary holder, and placed in the backyard of the selected site by the field staff. These stands were similar to the indoor stands, also composed of ¾ inch PVC piping, and situated at a height of 1.2m. A small sheltering device with an approximate diameter of 30cm was positioned accordingly to protect the monitor from any potentially adverse environmental conditions (i.e. high winds, precipitation, direct sunlight, etc.) (Figure 5).

The positions of the indoor and outdoor sampling stands and potential sources of contamination were noted on the floor plan. A guide on the appropriate positioning of indoor and outdoor stands can be found in Appendix E.

Personal monitors were placed on a lanyard, and positioned to lie within the breathing region of the subjects (Figure 6). During rest periods, volunteers were directed to place their monitor near their bedside table. In addition, during participation in activities in which there was a potential to damage the monitors (i.e. showering), or cause personal injury (i.e. playing sports), volunteers were asked to remove the monitor lanyard, and place it in a safe position in the same room. A summary of do's and don'ts regarding the handling of personal monitors can be found in Appendix F.

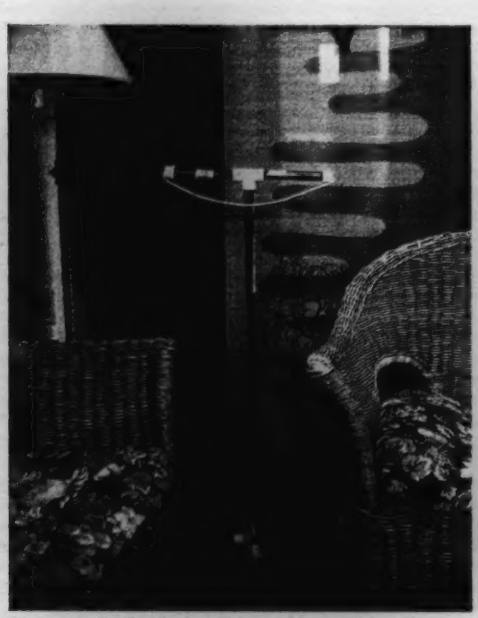


Figure 4. Indoor Sampling Stand

Figure 5. Outdoor Sampling Stand

Figure 6. Personal Monitor Lanyard

4.2.2 Sampling Protocols

The VOC monitors were deployed and retrieved according to the procedures listed in Appendix G. These protocols were established based on manufacturing suggestions (3M 1999) and from previous experience from other studies (Miyagawa and Kindzierski 2001, AHW 2000 a,b,c, Byrne 2000).

A field blank was deployed at every location to assist in QA/QC procedures. Approximately 45% of all samples deployed in the study were field blanks. The procedures for the deployment and retrieval of blanks can be found in Appendix G. A record of deployed passives, their location and timings were maintained on the Passive Log Sheet. An example of the passive log sheet can be found in Appendix H.

4.3 Air Exchange Measurements

The air exchange rates (arc) of the homes in this study were not measured. Davis and Otson (1996) reported that 24 selected homes in a 1991/1992 national survey of VOCs in Canadian homes and 44 Canadian homes during wintertime (January-February 1991) both reported arc values of 0.34 h^{-1}. These values were quite similar to those found in the baseline study (Miyagawa and Kindzierski 2001), which reported a mean of 0.39 h^{-1} and a median 0.30 h^{-1}. Based on the finding of theses two studies, it was assumed that the arc values from the baseline were a reasonable estimate to apply to this study.

4.4 Survey Instruments

4.4.1 Questionnaire

Questionnaires can provide information on the physical properties of an environment, and provide information on individual activity patterns, which allow for more accurate models and exposure assessments. However, it should be noted that sometimes there is a large difference in the understanding of questions between the questionnaire designer and the study person (Seifert 1995). Use of a standard questionnaire and checks within the survey can aid in decreasing this error. The TEAM study and Alberta Oil Sands Community Exposure Questions and Health Effects Assessment Program and baseline assessment (Alberta Health 2000a) served as a template for the format and questions in the HEMP questionnaire. Questions were posed in four areas of interest: (1) Demographics, (2) Household Characteristics and Exposure Sources, (3) Work Environment, and (4) General Health and Well Being. Questions were generated in a yes/no response, or check the box format to minimize interpretation error. The questionnaire was left with the participant at the deployment visit, and collected during the equipment retrieval visit. Though this data was collected, it was not used in the analysis for this report.

4.4.2 Time Activity Diary

When calculating exposure it is crucial to account for the contribution generated from personal activity. Time activity diaries can provide insight on where people spend their time (indoors, outdoors, at home, work or elsewhere, traveling) and potential exposure sources. This can assist in identifying and explaining abnormalities in the data.

Subjects were requested to complete a daily time activity diary for the duration of the sampling period. These diary sheets included a place for recording the start and end times, and selection of predetermined microenvironments (see Appendix I). Over each 24 hour period, participants were asked to fill in the approximate time slot, then check the activity box in which they were engaged. Activities were simplified into microenvironments which included the options of: indoors at home, outdoors at home, indoors at work, outdoors at work, indoors elsewhere, outdoors elsewhere, and traveling. The time activity diary was left with the volunteer during the set up visit, and collected at the take down visit. A field member assessed the completeness of the diary upon retrieval, and time recall estimates were used in cases where information was incomplete.

Validation of diary results is often difficult and subjective. Schwab et al. (1990) stated that if 20 to 28 hours were accounted for in each 24 hour period, their diary data was valid. Though this data was collected, it was not used in the analysis of this report.

4.5 Field Procedures

Each of the participating residences was visited by the Field team for two scheduled visits. The timing of these visits was scheduled during the recruitment visit, and confirmed by phone two days before the appointment. A reminder call was placed to the volunteer a few hours prior to the first visit.

The purpose of these visits was to complete the consent procedure, set up and retrieve monitors and time activity diaries. Sampling for sulphur dioxide (SO_2), nitrogen dioxide

(NO_2), ground level ozone (O_3), and particulate matter ($PM_{2.5}$) was conducted at the same time as the VOCs. This report only discusses the findings for selected VOCs. The BTEX compounds are reported in Hoeksema (2007).

4.5.1 Visit 1- Set Up

On the initial visit, one field team member explained the study, consent forms (Appendix J), and time activity diary to the participant, while the other member sketched the floor plan of the home. The participant was given a copy of guidelines for wearing the monitor (Appendix F) and instructions on how to fill out the time activity diary (Appendix I). These documents were reviewed with the participant. Any questions the participant had were answered at this time.

Monitor placement was selected according to protocol, and permission was obtained from the resident. These positions were then noted on the floor plan. The indoor and personal sampling equipment was set up, and monitors deployed according to protocol. Replicate and blank monitors were also deployed at this time.

Prior to departure, participants were booked in for their take down visit. The outdoor stand was positioned, and monitors deployed according to protocol. Replicate and blank monitors were also deployed at this time. The position of the outdoor stand was noted on the floor plan.

4.5.2 Visit 2- Take Down

The take down visit was scheduled for 7 days (~168h) following the set up appointment. During this visit, one field team member reviewed the time activity diary with the participant, and terminated the personal monitor as per protocol. The indoor monitors were terminated, as per protocol, and the stand disassembled and removed from the home by the second team member. Prior to leaving, the outdoor monitors were terminated, and the stand disassembled. All exposed monitors were taken back to the office for storage until shipment back to the lab. The remainder of the equipment was returned to the office for storage until the next deployment.

CHAPTER 5.0: SAMPLE ANALYSIS

5.1 Target Compounds

The vast number of VOCs potentially present in air samples would make a complete analysis lengthy and expensive. VOCs selected for the baseline assessment in Fort McKay (Miyagawa and Kindzierski 2001) included all the VOCs for which measurable quantities were attained in the initial pilot study, AOSCEHEAP (AHW 2000c). Three criteria were used in selecting the VOCs: (1) the local priority contaminants of concern, (2) national initiatives, and (3) the availability of technology to measure the contaminants (AHW 2000c).

Twelve major VOCs tested in the baseline study were monitored to determine any changes in concentration levels. This report will focus on the straight chain aliphatic compounds (hexane, heptane, octane, nonane, and decane), and 3-methylhexane. The selected compounds and rationale for selection are presented in Table 5. The remaining BTEX compounds are presented in Hoeksema (2007).

Table 5. Summary of selected VOCs and selection rationale*

Compound	Rationale	Sources
n-Hexane	Toxicity: respiratory irritation, BRI	Domestic and industrial solvents
n-Heptane n-Octane n-Nonane n-Decane 3-Methylhexane	Preliminary sampling on-site at oil sands indicated the presence of these compounds. Exposure measures in Fort McMurray/ Fort McKay will serve as potential markers for oil sands emissions (AHW 1997).	

* Adapted from Miyagawa and Kindzierski 2001

5.2 Analysis Procedures

Subsequent to exposure, samples were sent to the analytical laboratory for analyses. Analytes were removed from the carbon pad via exposure to a solvent solution. Analysis was then conducted on this extract through gas chromatography/mass spectrometry (GC/MS). Analysis procedures and services were provided by L. Butlin, Lab Supervisor, Centre for Toxicology (University of Calgary, Calgary, AB).

5.2.1 Shipping

Exposed monitors were stored at the field office in Fort McKay until the shipment date. Boxes of monitors were shipped on a bi-weekly basis via Puralator Courier Ltd. to the laboratory at the Centre for Toxicology in Calgary, Alberta. Each shipment contained copies of the Passive Data Log Form for the monitors which were included. These forms had the replicate labels removed from their original sheets (with their identification) and placed on separate sheets labelled "Replicates" to ensure the lab was blinded to the identity of the samples. Once received at the lab, samples were refrigerated at 4°C until the analyses could be performed.

5.2.2 Solvent Extraction

5.2.2.1 Extraction Procedures

Subsequent to exposure, the VOCs were desorbed from the adsorbent pad through the addition of 1.5 ml of carbon disulfide (CS_2) to each monitor. The monitors were then left for 30 minutes for the extraction process to proceed. Gentle agitation was induced every 10 minutes. The solution was then extracted into glass gas chromatography (GC) vials for

analysis.

5.2.2.2 Desorption Efficiencies

Knowing the desorption efficiency (also known as the recovery coefficient) is essential for accurately determining the amount of contaminant collected by the adsorbent. The desorption efficiency can be determined by adding a known weight of contaminant onto the adsorbent, then measuring the weight of contaminant recovered through the extraction process (3M 1999). Dividing the recovered weight by the known amount produces the recovery coefficient.

3M (1999) lists recovery coefficients for all the tested compounds, except for 3-Methylhexane, in the range of 1.04 to 1.09. Though, they recommend that these values be used only as a guideline, and that each laboratory establish their own recovery coefficients. Following the procedures outlined by the manufacturer (3M 1999), a recovery coefficient of 1.0 was determined and used in all calculations in this study.

5.2.3 Gas Chromatography/ Mass Spectrometry

Following extraction, the sample extracts were injected onto a gas chromatograph (GC) for compound separation followed by detection by a mass spectrometer (MS). A Hewlett-Packard (HP) GC-6890/MS-5973 was used. Separation was then performed in an HP 19091V-402 capillary column, measuring 25m x 200mm (inside diameter) x 1.12mm (film thickness). The oven temperature for the process ranged between 40 ^{o}C and 140 ^{o}C. Each sample extraction consisted of 1μL injection volume, and underwent a total run

time of 17.5 minutes.

5.3 Concentration Calculations

The GC/MS process yields the VOC concentrations in the extract volume (μg/mL). By multiplying this value by the extraction volume of 1.5 mL, and a conversion factor of 1000, the mass of analyte per monitor is attained (ng/badge). Passive sampling is typically conducted to determine time-weighted average (TWA) concentrations (Gorecki and Namiesnik 2002). Thus, the blank-corrected time-weighted concentration, C (μg/m^3), of the desired compound is calculated using the following equation:

$$C = \frac{M - m}{R \times t} \times 10^3 \qquad \text{Equation 7}$$

where M is the mass of the desired compound on the badge (ng), m is the average mass of compound on the blank badges (ng), R is the sampling rate (mL/min), and t is the duration of sampling (min). Sampling rates for all compounds were taken from 3M (1999), and can be found in Table 6.

Table 6. Sampling Rates (taken from 3M, 1999)

Compound	Sampling Rate (mL/min)
Hexane	32.0
3-Methylhexane	28.9
Heptane	28.9
Octane	26.6
Nonane	24.6
Decane	23.1

CHAPTER 6.0: RESULTS AND DISCUSSION

6.1 Sampling Overview

Sampling of contaminants was carried out at indoor, outdoor and ambient sites along with personal monitoring according to the procedures outlined in previous chapters. Measured concentrations depend strongly on the sampling strategy because both spatial and temporal variations occur (Wolkoff et al. 1997). Hence, spatial and temporal influences were considered during sampling to reduce the amount of bias and/or error in the sampling. Monitoring was conducted for a seven day period to encompass any temporal changes in exposure due to personal activity over the course of weekday and weekend. The length of this sampling period was also sufficient to readily collect low concentration air pollutants (WBEA 2006a).

In addition to the samplers placed in the field, a number of additional monitors were deployed for quality assurance and quality control. Several blanks were deployed to establish method detection limits (MDL), and replicates were used to assess the precision (repeatability) of the method. During the period between 07 September and 01 November 2006 a total of 225 VOC monitors were deployed in 35 homes in Fort McKay, AB. Raw results from these monitors can be found in Appendix K.

Meteorological conditions have been found to affect VOC concentrations and the performance of diffusive samplers. Daily temperature, wind speed and directions were collected from the air monitoring station on the north edge of town.

6.2 Analysis of Field Blanks

Over the course of the study 35 field blanks were deployed and collected. The Centre for Toxicology in Calgary conducted the analyses on the monitors. All results in the study were blank-corrected by subtracting the mean background concentration from the analytical result. The blank-corrected analysis results for the field blanks can be found in Appendix L.

6.2.1 Detection Limits

6.2.1.1 Method Detection Limits (MDL)

The method detection limit is the minimum concentration that can be measured and reported with confidence that the contaminant is actually present. The MDL, or limit of detection, is often determined through the variability of the blank levels (Kinney et al. 2002). In the CEHEAP program, three standard deviations above the mean method blank levels were used as the MDL (AHW 2006). In this study, the MDL of the passive samplers were based on field blanks, and the limit of quantification of the laboratory analysis. The limit of quantification for this method was 0.1 µg/mL. Any value below this amount was reported as 0µg/mL. The detection limits for VOCs were based on the laboratory limit of quantification (150 ng/sampler) when more than 90% of the field blanks were less than the limit of quantification. Table 7 summarizes the 168h MDL for each compound.

6.3 Precision

Precision is the closeness of repeated measurements to the same item (Zar 1999). To test the precision of the sampling method, replicates measurements were used. Over the study

period, 15 pairs of duplicates were made, 5 in each of the personal, indoor, and outdoor sets. Precision of the monitors was then estimated using the coefficient of variation (COV), or relative standard deviation (RSD) from the replicates. Only compounds for which both monitors were above the MDL were used in the calculations.

Table 7. Method detection limits (MDL) for selected compounds ($\mu g/m^3$)*

Compound	168h MDL
Hexane	0.47
3-Methylhexane	0.51
Heptane	0.51
Octane	0.56
Nonane	0.60
Decane	0.64

*Detection limits were based upon the laboratory limit of quantification (150 ng/sampler), based on a seven day (168h) sample period.

COV was calculated by the following equation:

$$COV = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100\% \qquad \text{Equation 8}$$

The resulting median COV for indoor samplers ranged from 0 to 7%, for outdoor samplers from 3 to 6%, and 0 to 2% for personal samplers (Table 8). A complete presentation of COVs for the monitors can be found in Appendix M. NIOSH (1994) reported that an acceptable level of precision for passive monitors is ± 25%. Compared to these criteria, the monitors used in this study demonstrated an acceptable level of precision.

Table 8. Summary of median COV for selected compounds

	Indoor		Outdoor		Personal	
Compound	N	Median COV (%)	N	Median COV (%)	N	Median COV (%)
Hexane	4	4	4	3	5	2
Heptane	3	3	3	6	5	0
Octane	3	4			4	0
Nonane	3	7				
Decane	3	0				
3-Methylhexane	4	3				

*N= the number of pairs above the LOQ

6.4 Sampling Conditions

Passive monitors can be significantly impacted by the sampling conditions they are deployed within. Temperature, wind conditions (speed, direction), humidity, and face velocity have all been documented as potentially biasing factors (Schlink et al. 2004).

6.4.1 Indoor Conditions

All indoor measurements were assumed to take place under normal conditions of 25°C and 760mm Hg, though no measurements were taken in this study. Based upon a literature review, Schlink et al. (2004) determined that exposure of the VOC monitors to unknown conditions (i.e. humidity, temperature, and linear velocity to the face of the sampler), may result in an error of ≤ 13%.

6.4.2 Outdoor Conditions

Meteorological parameters play an important part in ambient air quality. The parameters of interest are temperature, wind speed, wind direction and relative humidity. The objectives of an air monitoring program would not be complete if consideration was not given to the outdoor conditions. The Wood Buffalo Environmental Association operates a

permanent air monitoring station situated approximately 1km north of the community of Fort McKay (CASA 2007). This station monitors ambient levels of several air pollutants and meteorological data on a continual basis. Temperature (at 2m height), wind speed (at 10m height), wind direction (at 10m height), and relative humidity (%) are measured continuously over the year.

Figure 7 shows the daily average, maximum, and minimum temperatures incurred over the sampling period. From this figure it can be seen that there was a significant fluctuation in the overall temperature. A temperature difference of 34.1°C was experienced over the duration of the study. Though there was a large fluctuation in overall temperature, the OVM monitor has been found to perform well in temperatures within this range (Gagner 1996). The minimum recorded wind speed detected at the monitoring station was 0.2 km/h. This speed should still provide the necessary face velocity to prevent air stalling on the monitor surface. Hori and Tanaka (1996) determined that the performance of OVM 3500 was maintained down to face velocities of 0.01 m/sec (0.036 km/h). The daily average, maximum, and minimum temperatures and wind speeds observed over the study period are presented in Table 9.

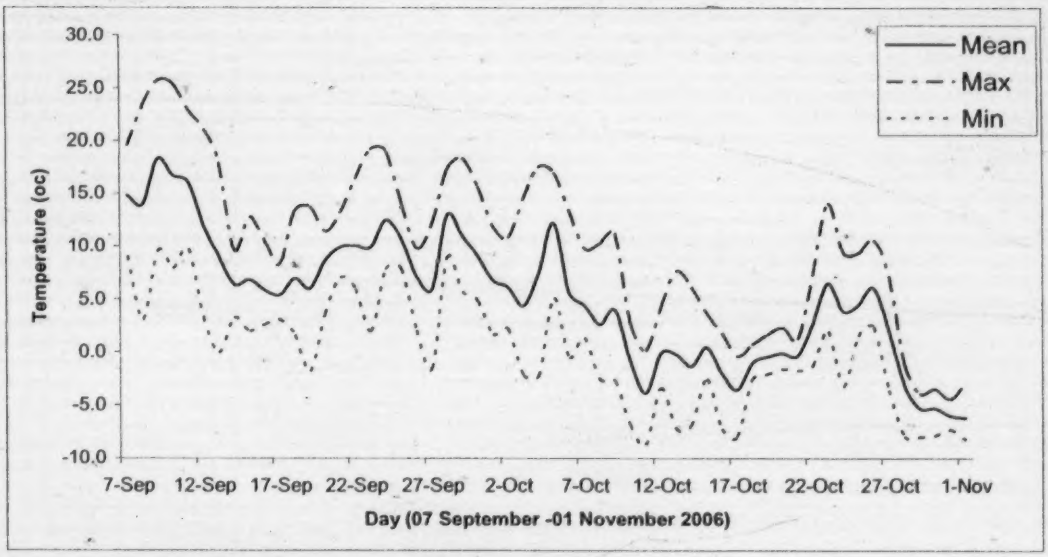


Figure 7. Daily mean, max, and min temperatures

Table 9. Average daily meteorological conditions

Temperature (°C)			Wind Speed (km/h)		
Mean	Maximum	Minimum	Mean	Maximum	Minimum
5.1	25.7	-8.4	11.5	32.5	0.2

6.5 Percent of Measurable Samples Above Detection Limits

Determining the proportion of monitors that detected contaminants above the MDL is useful in characterizing community exposure. A summary of the proportion of samples observed above the MDL is presented in Table 10. Most of the compounds were found at quite high rates in the indoor and personal monitors. Only nonane was detected in less than 50% of the indoor monitors. Hexane was the only compound that was detected in more than 50% of the monitors outdoors. Despite not being measurable, failure to detect a particular component remains useful in characterizing exposures.

Table 10. Proportion of samples above the MDL

Compound	Proportion Detected (%) (n=35)		
	Indoor	**Outdoor**	**Personal**
Hexane	100	54	100
Heptane	71	11	86
Octane	89	43	89
Nonane	46	17	63
Decane	69	0	66
3-Methylhexane	57	11	66

Typically, non detected samples have been censored from the data or reported as <MDL. However, many techniques have been established to treat samples in which the compound was not detected. One common practice to apply half of the respective LOD for each compound that was used in analyses (Edwards et al. 2001b, Jurvelin et al. 2001, Hornung and Reed 1990, Wallace et al. 1986). The USEPA (1998) suggests that this method of substitution is only applicable when there are less than 15% non detects. Data set with 15 to 50% non detects can be subjected to more complex methods, whereas 50 to 90% non detect data should be limited to tests of proportions. Further analysis is not suitable when there is less than 10% detection (USEPA 1998). In this study, only compounds with data sets >50% detection were used in the hypotheses testing.

6.6 Distributions

Data sets were assessed for normality. Frequency histograms and normal probability plots were generated for each compound and location (see Appendix N). Non-normal distributions with a right-skew (as seen in Figure 8) were observed in most of the histograms. Observation of non-normal distribution has been observed in several other exposure studies (Zhu et al. 2005, Schlink et al. 2004, Edwards et al. 2001b). Skewed

distributions with standard distributions exceeding the means, indicating the data do not follow a normal distribution, have also been observed by Kinney et al. (2002).

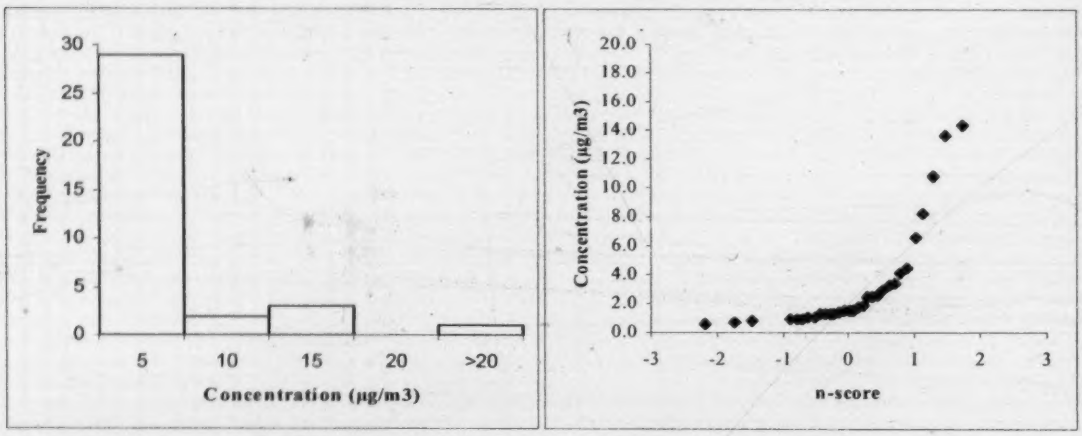


Figure 8. (a) Frequency histogram and (b) Normal probability plot for personal hexane levels

The right-skew is characteristic of log-normal data. Personal exposure distributions have been reported to follow log-normal distribution closer than normal distributions (Wallace et al. 1986). Hence, the data was log-transformed, and re-plotted to test for log-normality (See Appendix N). From Figure 9, it can be seen that the transformation failed to normalize the entire data set and the majority of histograms and retained their right-skewed appearance.

After a preliminary examination of the data, and on the basis of previously acquired knowledge about the populations (i.e., from the literature), it was concluded that the data did not follow a normal distribution. Since the underlying population is not approximately normally distributed, there is reason to believe that the parametric assumptions (independently and randomly collected data that is normally distributed, and has equal variances), do not hold for the population under study. Non- parametric tests are often referred to as distribution free statistics because they do not require that the data

fit a normal distribution (Zar 1999). These tests may be more powerful and more reliable, when application of parametric statistics is inappropriate.

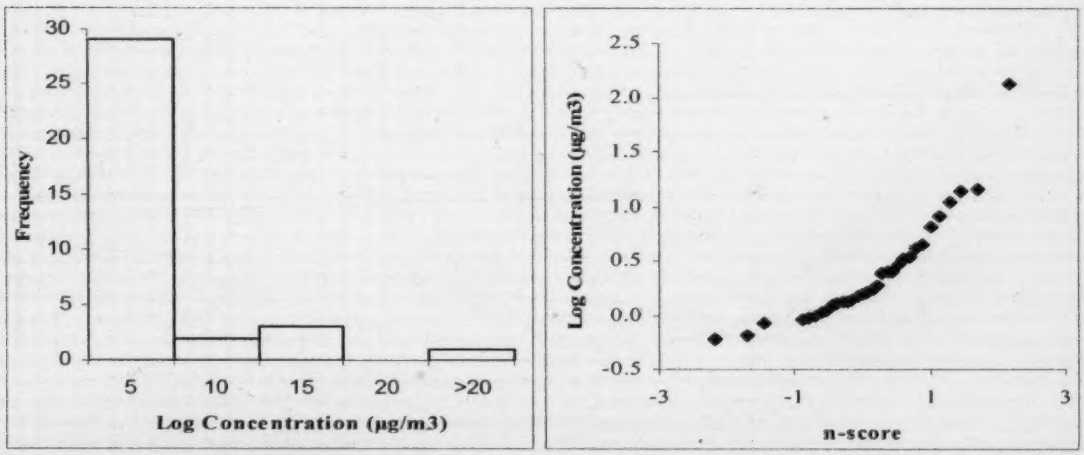


Figure 9. (a) Frequency histogram and (b) Normal probability plot for log transformed personal hexane levels

6.7 Descriptive Statistics

Relationships between microenvironments and personal exposure are often evaluated using median values. Though these values can provide general relationships, they do not provide an accurate representation of relationships in the upper end of exposure (Edwards et al. 2005). Thus, 90th percentiles were presented here to represent persons with high exposure levels. A summary of time weighted average (TWA) concentrations of the selected VOCs is presented in Table 11. Original data received from the lab were used in these calculations. Pollutants with less than 50% of the samples above the MDL are indicated with an asterisk (*) below. No outdoor monitors detected any level of decane at a detection limit of 0.64 µg/m^3, so summary statistics were not performed for the compound.

Table 11. VOC summary statistics 7-day TWA concentration (µg/m^3)

	Indoor (n=35)					
	Hexane	3-Methylhexane	Heptane	Octane	Nonane	Decane
Median	1.4	0.6	1.5	1.0	0*	0.8
90th Percentile	9.5	5.3	12.2	3.2	5.9	14.8
Maximum	149.5	41.7	55.7	51.1	25.4	22.4
	Outdoor (n=35)					
	Hexane	3-Methylhexane	Heptane	Octane	Nonane	Decane
Median	0.5	0*	0*	0*	0*	
90th Percentile	1.2	0.5	1.0	0.7	0.8	
Maximum	1.5	1.3	4.1	3.4	1.2	
	Personal (n=35)					
	Hexane	3-Methylhexane	Heptane	Octane	Nonane	Decane
Median	1.5	0.8	1.5	0.8	0.9	0.8
90th Percentile	10.9	4.5	7.7	4.7	4.2	11.1
Maximum	133.7	37.6	53.8	40.1	18.7	21.2

From the table it can be seen that there is relative similarity between observed personal and indoor values. This would suggest that indoor sources could be a significant contributing factor to personal exposure levels. Higher personal exposures amounts compared to indoor amount for the same averaging time may suggest that personal activities or sources/microenvironments outside the home exist. However, maximum observed values were consistently greater indoors, indicating that some potential hydrocarbon source existed within the home.

When the concentration of contaminant by location is plotted, strong relationships between indoor and personal samplers can be seen (Figures 10 to 15). No relationship to the outdoor samplers was observed for any of the contaminants, and a few contaminants

were not observed above detection levels in the outdoor samplers. Kinney et al. (2002) suggested that ambient levels are often the influencing factor for personal and indoor exposure. However, several studies have shown that ambient data are not a good predictor for estimating personal exposure levels (Repace 1982, AHW 2006, Kindzierski and Ranganathan 2006). These previous studies are more consistent with the findings in this study. Most of the VOCs outdoors were found below the detection limits, and thus were not at influential levels.

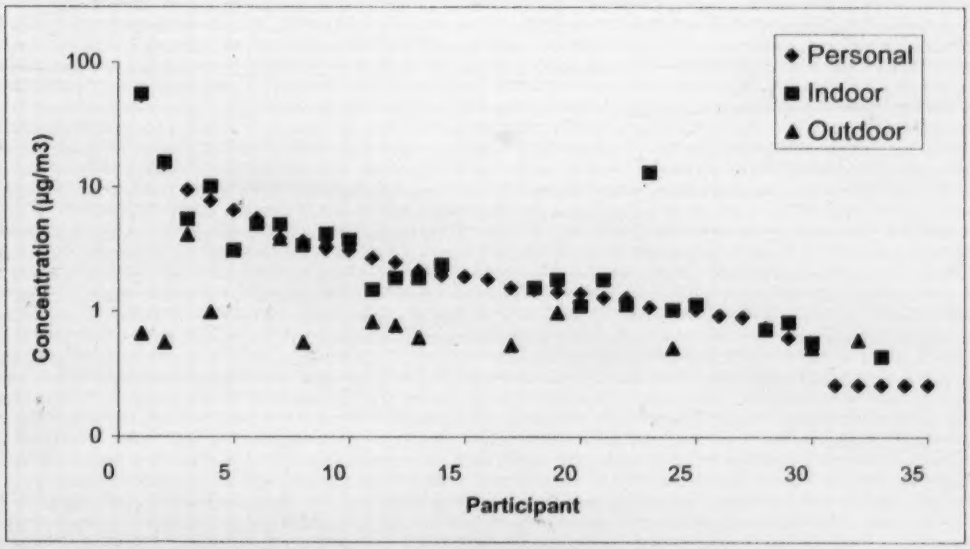


Figure 10. Relationship between hexane concentrations for three microenvironments (personal, indoor, and outdoor)

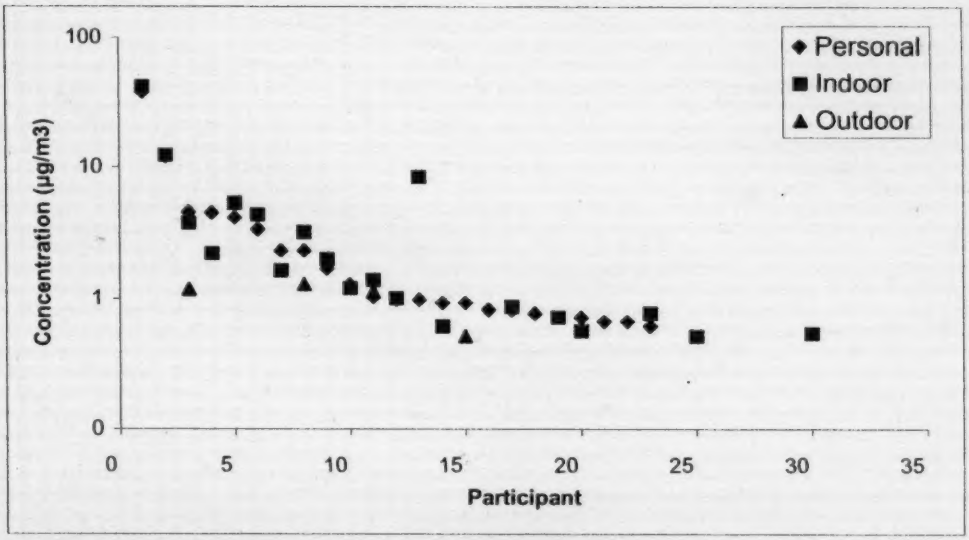


Figure 11. Relationship between 3-methylhexane concentrations for three microenvironments (personal, indoor, and outdoor)

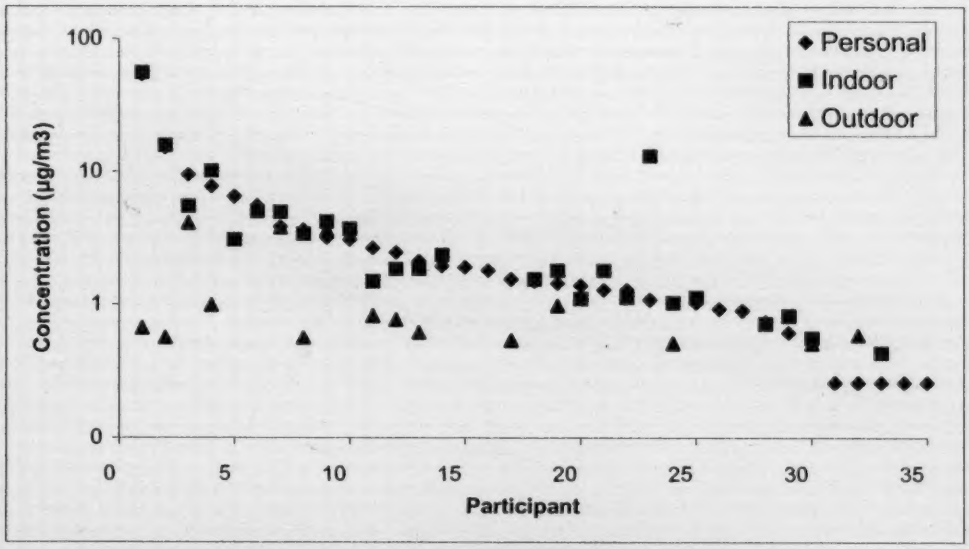


Figure 12. Relationship between heptane concentrations for three microenvironments (personal, indoor, and outdoor)

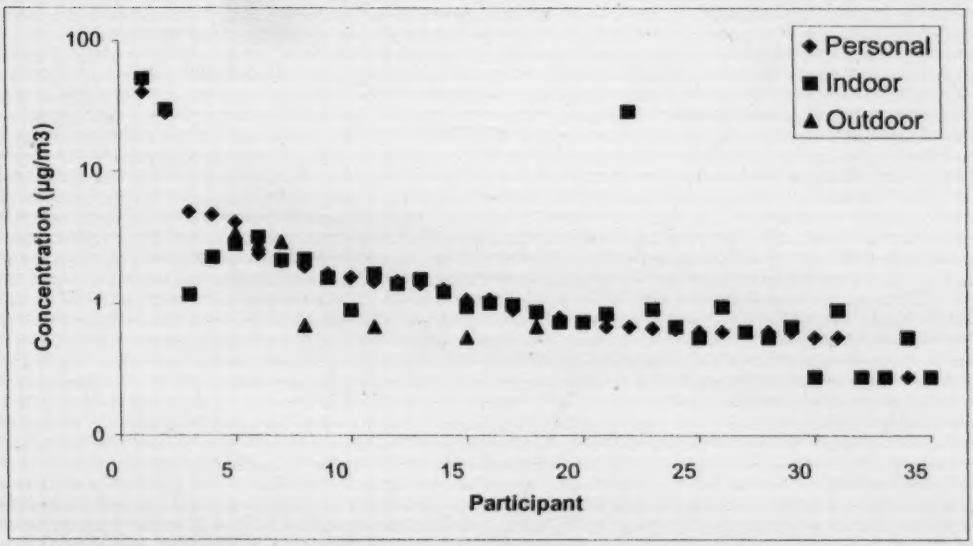


Figure 13. Relationship between octane concentrations for three microenvironments (personal, indoor, and outdoor)

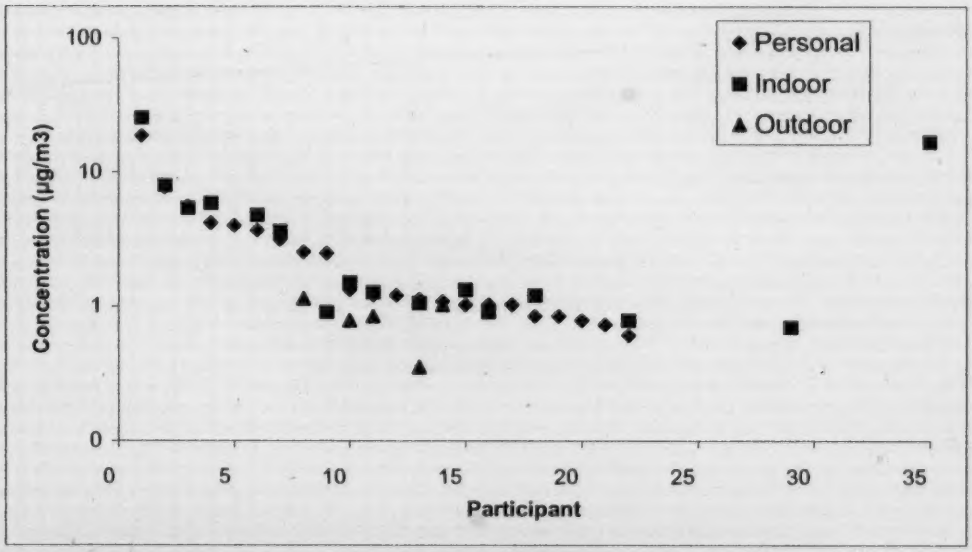


Figure 14. Relationship between nonane concentrations for three microenvironments (personal, indoor, and outdoor)

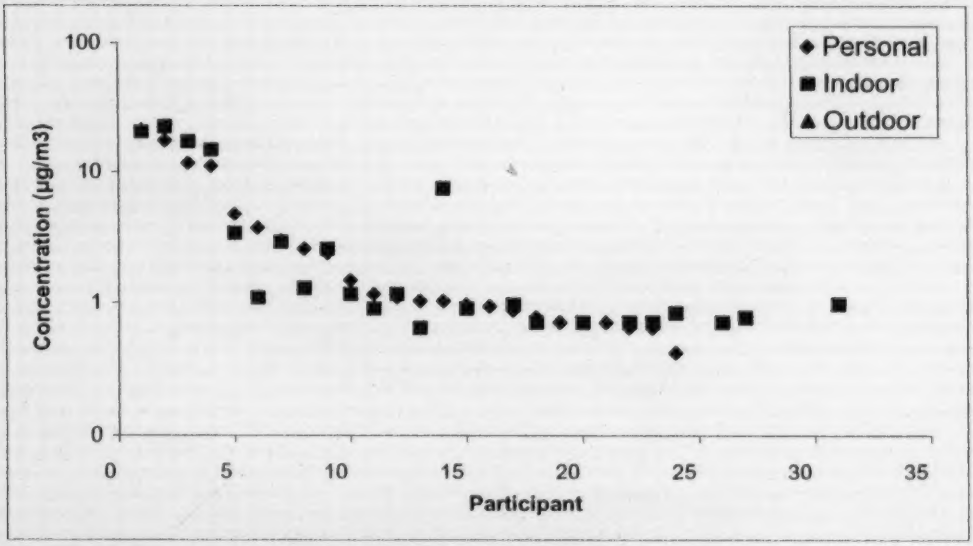


Figure 15. Relationship between decane concentrations for three microenvironments (personal, indoor, and outdoor)

6.7.1 Outliers

The range of concentrations detected was quite diverse for the individual VOCs. Extremely high levels, often several magnitudes greater than the 90th percentile were detected for almost all of the selected compounds. From Figures 10 to 15, it appears that there are measurements that may be interpreted as outliers in the data set. Normal application of an outlier test may remove the high-end exposure values, which are of greatest concern in exposure studies. To determine if the maximum values from this study represented true outliers, maximum values from the CEHEAP studies were used to compare the range of values obtained in the study (Table 12). From Table 12 it can be seen that the maximum values observed in the current Phase Two study were typically within the range of maximum values detected in similar studies through the province (e.g. AHW 2006, 2003, 2002, 2000, and Miyagawa and Kindzierski 2001).

Table 12. Maximum VOC concentration comparison (µg/m^3)

	Indoor Maximum					
	Fort McKay-Phase Two[a]	Fort McKay-Baseline[b]	Fort McMurray[c]	Grand Prairie[d]	Fort Saskatchewan[e]	Wabamun[f]
n	35	30	300	130	138	151
Hexane	149.5	71	101	40	35	28
3-Methylhexane	41.7	18	100	38	40	100
Heptane	55.7	17	70	90	70	80
Octane	51.1	42	25	20	300	35
Nonane	25.4	63	5	15	200	10
Decane	22.4	120	2000	33	1000	85
	Outdoor Maximum					
	Fort McKay-Phase Two[a]	Fort McKay-Baseline[b]	Fort McMurray[c]	Grand Prairie[d]	Fort Saskatchewan[e]	Wabamun[f]
Hexane	1.5	2.1* (3.2)	50	38	5	7
3-Methylhexane	1.3	2.2	5	1.5	2.5	1
Heptane	4.1	4.9	23	13	1.5	2
Octane	3.4	2.7	2.5	4	2.5	1
Nonane	1.2	0.9	5	4	1	0.1
Decane	0	0.0* (0.3)	40	10	3	2.5
	Personal Maximum					
	Fort McKay-Phase Two[a]	Fort McKay-Baseline[b]	Fort McMurray[c]	Grand Prairie[d]	Fort Saskatchewan[e]	Wabamun[f]
Hexane	133.7	30	100	95	450	50
3-Methylhexane	37.6	39	100	52	150	90
Heptane	53.8	43	100	85	150	75
Octane	40.1	95	150	20	500	40
Nonane	18.7	15	450	45	350	105
Decane	21.2	29	2500	75	1050	>1000

*detection limits are in brackets

[a] maximum of 168h air samples

[b] maximum of 24h personal and 96h indoor and outdoor air samples (Miyagawa and Kindzierski 2001)

[c] maximum of 96h air samples (AHW 2000)

[d] maximum of 168h air samples (AHW 2002)

[e] maximum of 168h air samples (AHW 2003)

[f] maximum of 168h air samples (AHW 2006)

Two points that stood out from the data set were the indoor hexane and indoor decane. The indoor hexane maximum concentration was higher than that observed in other studies, whereas the maximum indoor decane level was lower than the range observed in other studies.

Consideration as to the origin of the maximum concentrations as possible outliers should be made. These maximum values may be explained by three potential reasons: 1) they may be real, 2) there was some source of hydrocarbons near the monitor, or 3) they are erroneous data points. Since there was no access to the time activity and questionnaire data for this study, it was not impossible to distinguish a potential explanation for these results. Thus, either the values are real, or erroneous. With no means to distinguish between the two, there is no rationale for removing the points from the data set.

Furthermore, it has previously been established that the hypothesis testing will need to apply non-parametric statistics due to the non-normal distribution of the data. Maximum values and/or outliers have little to no influence on nonparametric analyses. In nonparametric paired tests and multi-sample tests, the largest and smallest data points are treated the same, regardless if they are accurate or an outlier (Zar 1999).

6.7.2 Comparison to Other studies

The results of the Phase Two Study in Fort McKay were compared to the results of the baseline assessment, and to other similar studies in Tables 13 to 15. Indoor VOC levels were compared to the indoor results from the baseline assessment (Miyagawa and

Kindzierski 2001), other Canadian homes (Otson et al. 1994), Dutch homes in Ede and Rotterdam, Netherlands (Lebret et al. 1986), samples collected in Ottawa City (Zhu et al. 2005), from the EXPOLIS study in Helsinki, Finland (Edwards et al. 2001b), and from German apartments in Leipzig, Munchen and Koln (Schlink et al. 2004) (see Table 13). Median observed concentrations of hexane, heptane and decane increased slightly from the fall baseline, whereas 3-methylhexane, octane and nonane decreased. Median observed indoor VOC levels observed in Fort McKay were lower than those observed in other studies.

Results for comparison of observed outdoor levels was similar (ie median outdoor VOC levels in Fort McKay were lower than those observed in other studies (see Table 14). As in the fall baseline assessment, Phase Two in Fort McKay failed to detect any levels of VOC contaminants above the MDL. Hexane was the only exception to this, where 0.5 $\mu g/m^3$ was detected, which was the MDL threshold. These values were comparable to those found in Dutch homes (Lebret et al. 1986), and in the City of Ottawa (Zhu et al. 2005). Levels of observed outdoor VOCs were substantially lower in the fall sampling sessions then in those conducted over the winter period (Miyagawa and Kindzierski 2001), and those detected the EXPOLIS study (Edwards et al. 2001b).

Personal VOC levels observed for 3-methylhexane and heptane dropped in more than half then those detected in the fall baseline assessment (Miyagawa and Kindzierski 2001) (see Table 15). The short exposure time in the baseline assessment (24h), resulted in the remainder of the compounds registering as below the MDL. Comparison to these values should be made with caution as the values may not provide an accurate representation of

the exposure level, due to the short exposure time. However, when compared to studies with longer exposure times, it can be noted that the levels for all the compounds in Fort McKay were substantially lower. The GerES II study (Hoffman et al. 2000) detected levels in excess of double those detected in Phase Two, and more than that in the EXPOLIS study (Edwards et al. 2001b).

Table 13. Comparison of Selected Indoor VOC Levels in µg/m^3*

	n	Hexane	3-Methylhexane	Heptane	Octane	Nonane	Decane
Fort McKay-Phase Two [a]	35	1.35	0.57	1.49	0.95	0*	0.77
Fort McKay Fall [b]	30	1.2* MDL=3.2	1.3	0.0* MDL=0.3	1.6	0.5	0.0* MDL=0.3
Fort McKay Winter [b]	30	4.3	3.1	6.0	3.8	2.2	1.1
Canadian Homes [c]	757	1.0					31.0
Dutch Homes [d]	134	4.0	2.0	3.0	2.0	4.0	9.0
City of Ottawa [e]	74						2.17
EXPOLIS [f]		*				2.13	5.26
German Apartments [g]	2103	3.1		2.3	1.0	1.4	3.0

[a] median of 168-hour indoor air samples
[b] median of 96-hour indoor air samples (Miyagawa and Kindzierski 2001)
[c] mean of 24-hour samples collected across Canada (Otson et al. 1994)
[d] median of 5-7 day samples inside homes in Ede and Rotterdam, Netherlands (Lebret et al. 1986)
[e] median of 24-hour samples collected in Ottawa City (Zhu et al. 2005)
[f] mean of 48-hour indoor exposure in Helsinki, Finland (Edwards et al. 2001b)
[g] median of 627-hour indoor exposure in Leipzig, Munchen and Koln, Germany (Schlink et al. 2004)
* detected in < 20% of samples

Table 14. Comparison of Selected Outdoor VOC Levels in µg/m^3*

	n	Hexane	3-Methylhexane	Heptane	Octane	Nonane	Decane
Fort McKay-Phase Two [a]	35	0.47	0*	0*	0*	0*	
Fort McKay Fall [b]	30	0.0* MDL=3.2	0.0* MDL=0.3	0.0* MDL=0.3	0.0* MDL=0.3	0.0* MDL=0.3	0.0* MDL=0.3
Fort McKay Winter [b]	30	2.3* MDL=3.2	1.8	3.6	2.5	1.4	0.0* MDL=0.3
Dutch Homes [c]	134	2.0	0.9	1.0	<0.3	<0.3	0.6
Canadian Homes [d]	754	0.72					47.53
City of Ottawa [e]	75						0.085
EXPOLIS [f]		4.51				1.06	1.11

[a] median of 168-hour outdoor air samples
[b] median of 96-hour outdoor air samples (Miyagawa and Kindzierski 2001)
[c] median of 5-7 day samples outside homes in Ede and Rotterdam, the Netherlands (Lebret et al. 1986)
[d] mean of 24-hour samples collected across Canada in Fall (Fellin and Otson 1994)
[e] median of 24-hour samples collected in Ottawa City (Zhu et al. 2005)
[f] mean of 48-hour outdoor exposure in Helsinki, Finland (Edwards et al. 2001b)

Table 15. Comparison of Selected Personal VOC Levels in µg/m^3*

	n	Hexane	3-Methylhexane	Heptane	Octane	Nonane	Decane
Fort McKay-Phase Two [a]	35	1.53	0.77	1.49	0.84	0.85	0.77
Fort McKay Fall [b]	30	5.1* MDL=13	1.8	4.6	0.0* MDL=1.2	0.0* MDL=1.3	0.0* MDL=1.4
Fort McKay Winter [b]	30	4.0* MDL=13	5.2	7.5	4.1	0.0* MDL=1.3	0.0* MDL=1.4
GerES II [c]	113	9.0	4.0	5.0	2.0	3.0	5.0
EXPOLIS [d]		3.79				8.02	16.50

[a] median of 168-hour personal air samples
[b] median of 24-hour personal air samples (Miyagawa and Kindzierski 2001)
[c] median of 168-hour samples in Germany (Hoffman et al. 2000)
[d] mean of 48-hour personal exposure in Helsinki, Finland (Edwards et al. 2001b)

6.8 Hypothesis Testing

A main hypothesis of this study is that increased industrial activity in the region has had no significant influence on the indoor, outdoor and personal levels of VOCs in the community of Fort McKay. Three hypotheses were tested in this study:

(1) levels of VOCs in indoor air are significantly greater than those in the outdoor air;

(2) levels of VOCs in personal air are not significantly greater than those in indoor air;

(3) levels of VOCs in indoor, outdoor and personal air are not significantly greater than those found in the baseline study.

For all hypothesis testing, replicate samples were averaged and the mean values used in the calculations.

6.8.1 Indoor-Outdoor Relationships

Looking at the descriptive statistics for Fort McKay (Figures 10 to 15, and Table 11), the selected VOCs presented in these Tables were detected more frequently, and at higher median concentrations indoors than outdoors. Other studies conducted by AHW within the region and province of Alberta have also consistently found indoor levels in excess of outdoors levels (AHW 2000, 2002, 2003, 2006). This trend has also been documented in other regions in Canada, the US and in several countries in Europe (Zhu et al. 2005, Schlink et al. 2004, Kinney et al. 2002, Edwards et al. 2001b, Hartwell et al. 1992, Lebret et al. 1986).

During the sampling session, only hexane was detected in >50% of the samples both indoors and outdoors. Formal hypothesis testing was limited to this compound.

6.8.1.1 Wilcoxon Signed Rank Tests

The Wilcoxon signed rank test is a non parametric test that is analogous to the parametric paired t-test. However, the Wilcoxon signed rank test retains its power when the assumptions of normality and presence of outliers has been violated. It involves the use of matched pairs, for example, before and after data, in which case it tests for a median difference of zero. Differences of zero between pairs are ignored in the analysis (Zar 1999).

The Wilcoxon signed rank test was designed to test a hypothesis about the location (median) of a population distribution. The Wilcoxon test is a very powerful test and has been used in several studies comparing paired environmental data sets (Violante et al. 2006, Schlink et al. 2004, Edwards et al. 2001b, Miyagawa and Kìndzierski 2001).

The Wilcoxon signed rank test was applied to the matched paired data to test the following null hypothesis:

H_o: There is no significant difference between indoor and outdoor hexane levels.

H_1: Indoor hexane levels are greater than outdoor hexane levels.

The test statistic was calculated in Excel according to procedures outlined in Zar (1999). As the direction of the test was predicted, the test was one-tailed, with a significance level of α=0.05. The number of non-zero differences (N), the calculated Wilcoxon signed

ranks test statistic (T_+); and probability (P), that T_+ is greater than or equal to the calculated value when H_o is true is presented in Table 16.

Table 16. Indoor-Outdoor Wilcoxon Signed Rank test for hexane

	N	T_+	P
Hexane	34	593	0.0001

For hexane, it can be seen that the probability is very small ($P<0.0001$), and the null hypothesis can be rejected at the significance level $\alpha=0.05$. It can be concluded that the indoor levels of hexane are significantly greater than those found outdoors. This is consistent with the baseline assessment and the findings of other studies that have shown indoor levels to be greater than those detected outdoors (Miyagawa and Kindzierski 2001).

6.8.1.2 Indoor/Outdoor Relationships

In order to further asses the relationship between indoor and outdoor VOC levels, ratios of median indoor/median outdoor concentrations were calculated. The larger the ratio is, the greater the contribution from indoor sources. For samples in which the median indoor or outdoor concentration was below the MDL, the MDL was substituted for the median concentration, and the ratio was then calculated. When both the indoor and out door medians were below the MDL, no ratio was calculated. Indoor/ outdoor ratios (I/O) for Phase One and other comparison studies are presented in Table 17.

Compared to the baseline, I/O ratios decreased for hexane, 3-methylhexane, and octane. Detection of heptane and decane allowed for I/O ratios for these two VOCs to be established. The high ratios for hexane (2.9) and heptane (2.9) indicate that there were

significant levels/sources of these compounds indoors. Lower ratios were calculated for 3-methylhexane, octane, and nonane (1.1, 1.7, and 1.2 respectively). It can be concluded that indoor concentrations were the predominant factor affecting personal exposure to the VOCs in this study. Intensive investigation on the origin of exposure sources by AHW (2006) has further suggested that other factors are of only minor relative importance.

Table 17. Indoor/Outdoor ratios (Adapted from Miyagawa and Kindzierski 2001)

	Indoor/Outdoor Ratios				
	Fort McKay-Phase Two[a]	Fort McKay-Baseline[b]		Dutch[c]	TEAM CA[d]
	Fall	Fall	Winter	Winter	Winter
Hexane	2.9	4.8	1.9	2	
3-Methylhexane	1.1	4.7	1.7	2	
Heptane	2.9		1.7	3	
Octane	1.7	5.5	1.5	>3	2.5
Nonane		1.4	1.6	>15	2.5
Decane	1.2		3.3	>15	2.7

[a]ratio of median indoor/median outdoor concentrations from Phase Two Study
[b]ratio of median indoor/median outdoor concentrations from Miyagawa and Kindzierski (2001)
[c] ratio of median indoor/median outdoor concentrations from Lebret et al. (1986)
[d] ratio of median indoor/median outdoor concentrations Hartwell et al. (1992)

6.8.2 Personal- Indoor Relationships

AHW (2000, 2002, 2003, 2006) determined that there was a strong relationship between personal and indoor levels, with indoor levels typically being slightly greater. Exposure to contaminants while working in/ passing through microenvironments during daily work and routines has been found to influence personal levels (Duan 1982). Since Canadians spend an average of 89% of their time indoors (Leech et al. 1997), it would be expected that personal levels would be comparable if not slightly greater than indoor

concentrations. However, wearing the monitor may have influenced the daily activity of the participant.

In this study, observed personal levels for hexane, 3-methylhexane, and nonane were slightly higher, and decane was the same as concentrations detected indoors. Looking at the detection rates (Table 10), heptane and 3-methylhexane were the only compounds detected in higher amounts in the personal monitors. Hexane and octane were detected in equal concentrations. Though octane was found at the same rate in both locations, it found in a slightly higher concentration indoors (0.95 $\mu g/m^3$) than in personal levels (0.84 $\mu g/m^3$). Decane was found at higher rates indoors than personal.

Formal hypothesis testing was limited to compounds that were detected in >50% of the monitors. The only compound which this eliminated was nonane.

6.8.2.1 Wilcoxon Signed Rank Tests

The Wilcoxon signed rank test was applied to the matched paired data to test the second hypothesis that personal levels of VOCs were not significantly greater than, and were closely related to indoor VOC levels:

H_o: There is no significant difference between personal and indoor VOC levels.
H_1: Personal VOC levels are greater than indoor VOC levels.

The test statistics were calculated in Excel according to the procedures outlined in Zar (1999). Differences of zero were ignored in the analysis (Zar 1999). As the direction of

the test was predicted, the test was one-tailed, with a significance level of α=0.05. The number of non-zero differences, N; the calculated Wilcoxon signed ranks test statistic (T_+); and probability (P), that T_+ is greater than or equal to the calculated value when H_o is true is presented in Table 18.

Table 18. Personal- Indoor Wilcoxon Signed Rank tests

	N	T_+	P
Hexane	33	286	0.461
3-Methylhexane	24	143	0.410
Heptane	33	265	0.229
Octane	33	261	0.401
Decane	26	165	0.390

At the 5% significance level, the null hypothesis cannot be rejected for any of the tested contaminants. It is concluded that there is no significant difference between personal and indoor levels for the selected VOCs observed in Fort McKay.

6.8.2.2 Spearman Rank-Order Correlation Coefficients

To determine the strength of the relationship between observed indoor and personal air concentration Spearman rank- order correlation coefficients (r^2) were calculated. A positive correlation indicates the presence of a relationship. The hypothesis tested:

H_o: There is no association between personal and indoor air VOC levels.

H_1: There is an association between personal and indoor air VOC levels.

The correlation coefficients were calculated in Excel according to the procedures outlined in Zar (1999). The number of non-zero differences, N; the calculated Spearman rank-

order correlation coefficient (r^2); and probability (P), that r^2 is greater than or equal to the calculated value when H_o is true is presented in Table 19.

Table 19. Personal – Indoor Spearman rank-order correlation coefficients

	N	r^2	P
Hexane	33	0.983	0.0036
3-Methylhexane	24	0.980	0.0250
Heptane	33	0.968	0.0016
Octane	33	0.881	0.0052
Decane	26	0.957	0.0116

At the 5% significance level, the null hypothesis can be rejected for the tested VOCs. It is concluded that there is a significant relationship between personal and indoor levels for the selected VOCs observed in Fort McKay.

6.8.3 Phase Two – Background Level Relationships

To date there have been no studies conducted that have allowed for a time lapsed comparison of indoor, outdoor and personal air concentrations from the same population. The EXPOLIS study (Helsinki) (Edwards et al. 2001a,b) compared levels obtained to those from other European countries. Study plans have been established to continue the HEMP, and CEHEAP projects in future years to collect long term exposure data (AHW 2006). This type of data collection is important in establishing baseline levels, and tracking the change in potential exposure over increased development activity and time.

One important aspect to take into consideration is the effect of exposure time, and proportions of measurements above the detection limit. Low levels of compounds outdoors were not captured in the low exposure times in the baseline assessment. With

longer exposure, the low levels were detected in the Phase Two study, which could then be interpreted as higher concentrations present than those in the Baseline assessment. This demonstrates the difficulty presented to researchers when attempting to compare data from different studies.

Concentrations collected in this study were compared to those collected in the Baseline Assessment conducted in 1999 by Miyagawa and Kindzierski (2001). Only those compounds that were detected in more than 50% of the monitors in both studies were used in formal hypothesis tests.

6.8.3.1 Mann Whitney U-Tests

As data set consisted of two sample sets, the Mann-Whitney U-Test was used to compare the two groups (Zar 1999). It was used to test the null hypothesis that all populations have identical distribution functions against the alternate hypothesis that one of the samples differed only with respect to location (median), if at all. The Mann-Whitney U-Test is one of the most powerful of the non-parametric tests for comparing two populations. If there are only two populations being tested, the Mann-Whitney U-Test is identical to the Kruskal-Wallis test, but somewhat easier to apply (Zar 1999). The Mann-Whitney U-test has previously been applied in exposure analyses (Schlink et al. 2004).

The Mann Whitney U- test was applied to data from the Baseline and Phase Two studies to test the following null hypothesis:

H_o: The VOC concentration in Phase Two is not significantly greater than in the Baseline.

H_1: The VOC concentration in Phase Two is significantly greater than in the Baseline. The test statistics were calculated in Excel according to the procedures outlined in Zar (1999). The significance level of the tests was set at α=0.05. Since the levels of VOC were predicted to be higher in Phase Two than in the Baseline, the test is one-tailed. Thus, the Mann-Whitney statistic for U^1 was used in the test. Table 19 lists the calculated Mann-Whitney U-test statistic (U^1) and the probability (P) that U^1 is greater than or equal to the calculated value when H_o is true.

Table 20. Phase Two-Baseline Mann-Whitney U-Tests

	Indoor		Outdoor		Personal	
	U^1	P	U^1	P	U^1	P
3-Methylhexane	132	0.0500	*	*	30	7.237e-07
Heptane	*	*	*	*	64	< 1e-06
Octane	166	0.0001	*	*	*	*

*= compound not detected in 50% of monitors in both studies

Indoor 3-methylhexane and octane, and personal levels of 3-methylhexane and heptane were detected in more than 50% of samples in both the Baseline Assessment and Phase Two studies. Looking specifically at these compounds in this test, at the 5% significance levels, there is a significant increase in concentration levels between the two groups. It can be concluded that indoor levels of 3-methylhexane and octane, and personal levels of 3-methylhexane and heptane have increased from the Baseline study. No outdoor levels were observed above the MDL. This supports the finding of Ott and Roberts (1998) who found that large point source industrial locations have less influence on exposure than personal activity and indoor sources.

CHAPTER 7.0: CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study was to compare the levels of selected VOCs to those collected in the baseline assessment in the community of Fort McKay, AB. Additionally it was assessed if levels of VOCs were greater at indoor locations compared to outdoor locations.

Analysis was conducted on hexane, 3-methylhexane, heptane, octane, nonane, and decane. Initial statistical analysis found the data set to be non-normally distributed. Application of non-parametric statistics was used to account for this. Maximum values were found to be within the range detected in other studies conducted throughout Alberta.

All the selected VOCs in the personal and indoor locations were detected in more than 50% of the samples above the MDL. Only hexane was detected in more than 50% of the samples above the MDL in the outdoor location.

Median values are often used to evaluate relationships between microenvironments and personal exposure. Indoor values ranged from 0.6 to 1.4 $\mu g/m^3$, and personal values between 0.8 to 1.5 $\mu g/m^3$. A strong relationship was observed between indoor and personal concentration levels.

The Wilcoxon signed rank test was performed to test the relationship between indoor and outdoor concentrations. Only hexane was examined, as it was the only compound that was detected in >50% of samples both indoors and outdoors. Overall, a statistically significant difference between indoor and outdoor levels of hexane was found

($P<0.0001$). Hypothesis testing of indoor versus outdoor hexane levels indicated higher indoor levels in Fort McKay. This is consistent with the baseline assessment and the findings of other studies that indicated higher VOC levels dominate indoors rather than outdoors.

This relationship was further examined by calculating indoor to outdoor ratios of the compounds. Estimated median indoor/median outdoor air concentration ratios for all VOCs observed were greater than one. These results strongly suggest that important indoor sources of VOCs existed in the homes tested. Both of these findings of the Phase Two study are consistent with findings observed in the baseline study and with scientific literature. These findings tend to indicate that indoor sources are important contributors to the origins of VOCs observed indoors and to personal exposure.

The relationship between personal exposure and indoor air was also tested by the Wilcoxon signed rank test. At the 5% significance level, it was concluded that there is no significant difference between observed personal and indoor levels in Fort McKay in the Phase Two study. Referring to the observed median concentrations (Table11), indoor and personal values were quite similar. Spearman rank-order correlation coefficients were calculated, and found a strong positive correlation between personal and indoor exposure. This suggests that the participants potentially spent an increased amount of time within their homes, resulting in similar detection levels. In addition, it is nearly impossible to verify if the monitor was worn for the duration of the study, or if it was left within the home. This may result in similar indoor- personal values, and results in an underestimation of exposure. This contradicts the findings of the Baseline and other

studies, which found personal levels to be higher than indoor levels (Edwards et al. 2005, Edwards et al. 2001b, Miyagawa and Kindzierski 2001).

The main objective of this study was to determine if there was any significant increase in VOC concentrations from the Baseline study. Since data were not paired, the Mann-Whitney U-test was applied to data sets which had >50% detection. One might predict increased VOC emissions in the regional area are associated with increased oil sand industrial activity from time when the Baseline study was conducted and the time when the Phase Two study was conducted. The microenvironment that one would expect to be influenced the greatest is the outdoor environment (the environment to which industrial VOCs are emitted directly into). Significant increases in observed levels of indoor 3-methylhexane ($P \leq 0.05$), octane ($P<0.0001$), and personal levels of 3-methylhexane ($P<0.0001$) or heptane ($P<0.0001$) were detected. However, outdoor VOC levels observed in baseline study and the Phase Two study were too small – in many instances many samples were below detection limits. This is consistent with scientific literature reporting that large point source industrial activities have less influence on exposure than personal activity and indoor sources (Ott and Roberts 1998, Wallace et al. 1986).

Finally, outdoor VOC levels in the Phase Two study were too low to attempt any hypothesis testing of relationships between outdoor and personal air concentrations. This does not limit findings stated above as again scientific literature has reported that personal air concentrations show stronger relationships to indoor concentrations compared to outdoor concentrations (AHW 2006, Kinney et al. 2002).

There have been few population-based surveys to determine the extent and magnitude of population VOC exposures both within populations over time and between different populations. Without such information combined with information on health effects, it is difficult to establish guidelines for levels of VOC compounds in different microenvironments and permissible emission levels from different materials. Indoor VOC pollution has no existing legal threshold values, with the exception of a few components. Alberta does not have air quality objectives for 24-hour ambient concentrations of VOCs. Some one-hour objectives for select VOCs have been determined. However, personal exposure levels have yet to be established due to the relatively new nature of this methodology/technology. Establishing consistent, longer exposure times, will assure to capture a true representation of exposure. Increased detection ability will allow for further comparisons between studies.

CHAPTER 8.0: REFERENCES

3M. 1996. Air Monitoring Guide. St. Paul, MN: 3M Occupational Health and Environmental Safety Division.

Alberta Health and Wellness (AHW). 2007. Wood Buffalo Environmental Association Human Exposure Monitoring Program: Part I Methods Report. Part II 2005 Monitoring Year Results. [online]. Alberta Health and Wellness, Edmonton, AB. http://www.health.gov.ab.ca/resources/publications/index.html [accessed March 2007].

Alberta Health and Wellness (AHW). 2006. The Wabamun and Area Community Exposure and Health Effects Assessment: Final Report [online]. Alberta Health and Wellness, Edmonton, AB. http://www.health.gov.ab.ca/resources/publications/index.html [accessed December 2006].

Alberta Health and Wellness (AHW). 2003. Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program: Final Report [online]. Alberta Health and Wellness, Edmonton, AB. http://www.health.gov.ab.ca/resources/publications/index.html [accessed December 2006].

Alberta Health and Wellness (AHW). 2002. The Grand Prairie and Area Community Exposure and Health Effects Assessment: Final Report [online]. Alberta Health and Wellness, Edmonton, AB. http://www.health.gov.ab.ca/resources/publications/index.html. [accessed December 2006].

Alberta Health and Wellness (AHW). 2000a. The Alberta oil sands community exposure and health effects assessment program: Methods Report [online]. Alberta Health and Wellness, Edmonton, AB. Available from http://www.health.gov.ab.ca/resources/publications/index.html.[accessed December 2006].

Alberta Health and Wellness (AHW). 2000b. The Alberta oil sands community exposure and health effects assessment program: Summary Report [online]. Alberta Health and Wellness, Edmonton, AB. Available from http://www.health.gov.ab.ca/resources/publications/index.html.[accessed December 2006].

Alberta Health and Wellness (AHW). 2000c. The Alberta oil sands community exposure and health effects assessment program: Technical Report [online]. Alberta Health and Wellness, Edmonton, AB. Available from http://www.health.gov.ab.ca/resources/publications/index.html.[accessed December 2006].

Alberta Health and Wellness (AHW). 1997. The Alberta oil sands community exposure and health effects assessment program: Pilot Study [online]. Alberta Health and Wellness, Edmonton, AB. Available from http://www.health.gov.ab.ca/resources/publications/index.html.[accessed December 2006].

Begerow, J., Jermann, E., Turkan, K., Dunemann, L. 1999. Performance of two different types on passive samplers for the GC/ECD-FID determination of environment; VOC levels in the air. Fresenius Journal of Analytical Chemistry 363: 399-403.

Brooks, B., and Davis, W. 1992. Understanding Indoor Air Quality. CRC Press Inc., Boca Raton, FL.

Brown, R. 2000. Monitoring the ambient environment with diffusive samplers: theory and practical considerations. Journal of Environmental Monitoring 2: 1-9.

Byrne, C. 2000. Air Sampling of Volatile Organic Compounds in a Community Near an Industrial Corridor. M.Sc. Thesis, University of Alberta, Edmonton, AB. 165 pp.

Cheperdak, L. and Hoeksema, G. 2006. Personal Communication with project partner. University of Alberta, Edmonton, AB (August 2006).

Clean Air Strategic Alliance (CASA). 2007. Clean air strategic alliance data warehouse [online]. CASA, Edmonton, AB. Available from http://www.casadata.org [accessed 20 February 2007].

Cruz, L., Campos, V., Silva, A, and Tavares, T. 2004. A field evaluation of a SO2 passive sampler in tropical industrial and urban air. Atmospheric Environment 38: 6425–6429

Davis, C., and Otson, R. Estimation of emissions of volatile organic compounds (VOCs) from Canadian residences. Volatile Organic Compounds in the Environment. 1996. In Wang, W., Schnoor, J., Doi, J., (editors). American Society for Testing and Materials, Philadelphia, PA. pp 55-65.

Duan, N. 1982. Models for human exposure to air pollution. Environment International 8: 305-309.

Edwards, R., Jurvelin, J., Koistinen, K., Saarela, K., Jantunen, M. 2001a. VOC source identification from personal and residential indoor, outdoor and workplace microenvironment samples in EXPOLIS-Helsinki, Finland. Atmospheric Environment 35: 4829-4841.

Edwards, R., Jurvelin, J., Koistinen, K., Saarela, K., Jantunen, M. 2001b. VOC concentrations measured in personal samples and residential indoor, outdoor and

workplace microenvironments in EXPOLIS-Helsinki, Finland. Atmospheric Environment 35: 4531-4543.

Edwards, R., Schweizer, C., Jantunen, M., Lai, H., Bayer-Oglesby, L., Katsouyanni, K., Nieuwenhuijsen, M., Saarela, K., Sram, R., and Künzli, N. 2005. Personal exposures to VOC in the upper end of the distribution—relationships to indoor, outdoor and workplace concentrations. Atmospheric Environment 39: 2299-2307.

EnHealth. 2002. Environmental health risk assessment: Guidelines for assessing human health risks from environmental hazards. Goanna Print Ltd, Canberra, Australia.

Gagner, R. 1996. Validation of a Passive Air Sampling Device for Measuring Ambient VOCs at Subzero Temperatures. M.Sc. Thesis, University of Alberta, Edmonton, AB. 196 pp.

Gonzalez-Flesca, N., Bates, M., Delmas, V., and Cocheo, V. 2000. Benzene exposure assessment at indoor, outdoor and personal levels. The French contribution to the life Macbeth programme. Environmental Monitoring and Assessment 65: 59-67.

Górecki, T., and Namiesnik, J. 2002. Passive sampling. Trends in Analytical Chemistry, 21(4): 276-291.

Harper, M., and Purnell, C. J. 1987. Diffusive sampling – a review. American Industrial Hygiene Association Journal 48: 214-218.

Hartwell, T. , Perritt, R., Pellizzari, E., and Michael, L. 1992. Results from the 1987 total exposure assessment methodology (team) study in Southern California. Atmospheric Environment. Part A 26(8): 1519-1527.

Hoeksema, G. Atmospheric BTEX in Fort McKay, AB: A Comparison With Baseline Measurements. M.Sc. Thesis, University of Alberta, Edmonton, AB. 114 pp.

Hoffmann, K., Krause, C., Seifert, B., and Ullrich, D. 2000. The German Environmental Survey 1990/92 (GerES II): Sources of personal exposure to volatile organic compounds. Journal of Exposure Analysis & Environmental Epidemiology 10(2):115-125.

Hori, H., and Tanaka, I. 1996. Effect of face velocity on performance of diffusive samplers. Annals of Occupational Hygiene 40: 467-476.

Hornung, P., and Reed, L. 1990. Estimation of average concentration in the presence if nondetectable values. Applied Occupational and Environmental Hygiene 5(1): 46-51.

International Programme on Chemical Safety (IPCS) 2006. n-Hexane. Available from: http://www.inchem.org/documents/ehc/ehc/ehc122.htm [accessed 10 February 2006].

Jantunen M., Hanninen O., Koistinen, K., and Hashim, J. 2002. Fine PM measurements: personal and indoor air monitoring. Chemosphere 49: 993–1007.

Jurvelin, J., Edwards, R., Saarela, K., Laine-Ylijoki, J., DeBortoli, M., Oglesby, L., SchlaÈpfer, K., Georgoulis, L., Tischerova, E., HaÈnninena, O., and Jantunend, M. 2001. Evaluation of VOC measurements in the EXPOLIS study. Journal of Environmental Monitoring 3: 159-165.

Kindzierski, W., and Raganathan. H. 2006. Indoor and outdoor SO_2 in a community near oil sand extraction and production facilities in northern Alberta. Journal of Environmental Engineering and Science 5 (S1): 121-129.

Kindzierski, W., Probert, S., and Byrne-Lewis, C. 2000. Volatile Organic Compounds in Outdoor and Indoor Air at Residences in Sherwood Park and St Albert, Alberta. Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB. May 2000. 220 pp.

Kinney, P., Chillrud, S., Ramstrom, S., Ross, J., and Spengler, J. 2002. Exposures to multiple air toxics in New York City. Environmental Health Perspectives 110(4): 539-546.

Krupa, S., and Legge, A. 2000. Passive sampling of ambient, gaseous air pollutants: an assessment from an ecological perspective. Environmental Pollution 107: 31-45.

Leaderer, B., Zagraniski, B., Berwick, M., and Stolwijk, J. 1986. Assessment of exposure to indoor air contaminants from combustions sources: methodology and application. American Journal of Epidemiology 124(2): 275-289.

Lebret, E., van de Wiel, H. J., Bos, H. P., Noij, D., and Boleij, J. S. M. 1986. Volatile organic compounds in Dutch homes. Environment International 12: 323-332.

Leech, J., Wilby, K., McMullen, E., and Laporte, K. 1997. The Canadian human activity pattern survey: report of methods and population surveyed. Chronic Diseases in Canada 17(3/4): 118-123.

Mattuck, R., Blanchet, R., and Wait, D. 2005. Data representativeness for risk assessment. Environmental Forensics 6: 65–70.

Mac Berthouex, P. and Brown, L.C. 2002. Statistics for Environmental Engineers, 2nd Edition. Lewis publishers, Boca Raton, FL. 489pp.

Miyagawa, R. and Kindzierski, W. 2001. Personal, indoor, and outdoor monitoring of volatile organic compounds in the community of Fort McKay, Alberta: A baseline assessment. Masters thesis (unpublished), Department of Civil and Environmental Engineering, University of Alberta.

Molhavé, L., Bach, B., and Pedersen, O. 1986. Human reactions to low concentrations of volatile organic compound. Environment International 12: 167-175.

Moschandreas D., and Saksena S. 2002. Modeling exposure to particulate matter. Chemosphere 49: 1137 –1150.

Muller, J. 1992. Geographical distribution and seasonal variation of surface emissions and deposit velocities of atmospheric trace gases. Journal of Geophysical Research 97: 3787-3804.

National Academy of Science (NAS). 1991. Human Exposure Assessment for Airborne Pollutants: Advances and Opportunities, National Academy Press, Washington, DC.

National Emission Inventory and Projection Task Group. 1995. NEIPTG Consensus Forecast on Emissions of NO_x, VOC and SO_2 (1990-2010). Environment Canada, Ottawa.

National Institute for Occupational Health and Safety (NIOSH). 1994. NIOSH manual of analytical methods, 4th edition. DHHS (NIOSH) Publication 94-113. NIOSH, Atlanta, GA. August 1994.

Otson, R. and Meek, B. 1995. National Indoor Air Quality Survey- Implications for Health. In: Flaitheim, G., Gerg, K., and Edvardsen, K. (editors). Proc. Indoor Air Quality in Practice- Moisture and Cold Climate Solutions. Moberg and Helli. 1995. pp 322-331.

Otson, R., Fellin, P., and Tran, Q. 1994. VOCs in representative Canadian residences. Atmospheric Environment 28(22): 3563-3569.

Otson, R., and Fellin, P. 1992. Volatile organics in the indoor environment: sources and occurrence. In: J. O. Nriagu (ed.). Gaseous Pollutants: Characterization and Cycling: 335-421. New York, NY: John Wiley & Sons.

Ott, W., Wallace, L., Mage, D., Akland, G., Lewis, R., Sauls, H., Rodes, C., Kleffman, D., Kuroda, D., and Morehouse, K. 1986. The environmental protection agency's research program on total human exposure. Environment International 12(1-4): 475-494.

Ott, W., and Roberts, J. 1998. Everyday exposure to toxic pollutants. Scientific American 278(2): 72-77.

Oury, B., Lhuillier, F., Protois, J., and Mor´ele, Y. 2006. Behaviour of the GABIE, 3M 3500, PerkinElmer Tenax TA, and RADIELLO 145 Diffusive Samplers Exposed Over a Long Time to a Low Concentration of VOCs. Journal of Occupational and Environmental Hygiene 3: 547–557.

Partyka, M., Zabiegala, B., Namiesnik, J., and Przyjazny, A. 2007. Application of passive samplers in monitoring of organic constituents of air. Critical Reviews in Analytical Chemistry 37: 51-78.

Pellizzari, E., Hartwell, T., Perritt, R., Sparacino, C., Sheldon, L., Zelon, H.., Whitmore, R., Breen, J., and Wallace, L. 1986. Comparison of indoor and outdoor residential levels of volatile organic chemicals in five U.S. geographical areas. Environment International 12(6): 619-623.

Repace, J. 1982. Indoor air pollution. Environment International 8(1-6): 21-36.

Sack, T., Steele, D., Hammerstrom, K., and Remmers, J. 1992. A survey of household products for volatile organic compounds. Atmospheric Environment 26(6):1063-1070.

Samet, J., and Lambert, W. 1991. Epidemiological approaches for assessing health risks from complex mixtures in indoor air. Environmental Health Perspectives 95: 71-74.

Scheff, P., and Wadden, R. 1993. Receptor modeling of VOCs: I, Emission inventory and validation. Environmental Science and Technology 27: 617–625.

Schlink, U., Rehwagena, M., Dammb, M., Richtera, M., Bortec, M., and Herbarth, O. 2004. Seasonal cycle of indoor-VOCs: comparison of apartments and cities. Atmospheric Environment 38:1181-1190.

Schneider, P., Gebefugi, I., Richter, K., Wolke, G., Schnelle, J., Wichmann, H.-E., and Heinrich, J. 2001. Indoor and outdoor BTX levels in German cities. The Science of the Total Environment 267: 41-51.

Schwab, M., Colome, S.D., Spengler, J.D., and Ryan, P.B.1990. Activity patterns applied to pollutant exposure measurement: data from a personal monitoring survey in Los Angeles, Toxicological and Industrial Health 6:517-132.

Seifert, B. 1995. Validity criteria for exposure assessment methods. The Science of the Total Environment 168:101-107.

Seifert, B., and Abraham, H. 1989. Indoor air concentrations of benzene and some other aromatic hydrocarbons. Ecotoxicology and Environmental Safety 6: 190-192.

Shell Canada. 2006. Sustainable Choices, Stakeholder Voices. 2005 Sustainable Development Report. March 2006. Shell Canada Ltd, Calgary, AB, 85pp.

Statistics Canada. 2007. 2006 Community Profiles. Available from http://www12.statcan.ca/english/census06/data/profiles/community/Details/Page [accessed 20 March 2007].

Stuart, A., 1984. The Ideas of Sampling. Oxford University Press. New York, NY. 91 pp.

Suncor Energy Inc. 1998. Project Millennium Application Environmental Impact Assessment. Suncor Energy Inc., Calgary, AB. April 1998.

Suncor Energy Inc. 2007. 2006 Annual Report. Suncor Energy Inc., Calgary, AB. March 2007. 122pp.

Syncrude Canada Ltd. 2006. 2005 Sustainability Report; A New Generation of Opportunity. Syncrude Canada Ltd. Fort McMurray, AB. 68pp.

US EPA. 1998. Guidance for Data Quality Assessment: Practical Methods for Data Analysis EPA QA/G-9. EPA/600/R-96/084. United States Environmental Protection Agency, Washington, D.C

Violante, F., Barbieri, A., Curti, S., Sanguinetti G., Graziosi, F., and Mattioli, S. 2006. Urban atmospheric pollution: Personal exposure versus fixed monitoring station measurements. Chemosphere 64: 1722–1729.

Wallace, L. 2001. Human exposure to volatile organic pollutants: Implications for indoor air studies. Annual Review Energy Environment 26: 269-301.

Wallace, L. 1991. Comparison of risks from outdoor and indoor exposure to toxic chemicals. Environmental Health Perspectives 95: 7-13.

Wallace, L., Pellizzari, E., Hartwell, T., Sparacino, C., Whitmore, R., Sheldon, L., Zelon, H., and Perritt, R. 1987a. The TEAM Study: Personal exposures to toxic substances in air, drinking water, and breath of 400 residents of New Jersey, North Carolina, and North Dakota. Environmental Research 43(2): 290-307.

Wallace, L. A., Pellizzari, E., Leaderer, B., Zelon, H., and Sheldon, L. 1987b. Emissions of volatile organic compounds from building materials and consumer products. Atmospheric Environment, 21(2): 385-393.

Wallace, L., Pellizzari, E., Hartwell, T., Whitmore, R., Sparacino, C., and Zelon, H. 1986. Total exposure assessment methodology (TEAM) study: personal exposures, indoor-outdoor relationships, and breath levels of volatile organic compounds in New Jersey. Environment International 12: 369-387.

Wolkoff, P., Clausen, P., Jensen, B., Nielsen, G., and Wilkins, C. 1997. Are we measuring the relevant indoor pollutants? Indoor Air 7: 92-106.

Wolkoff, P., and Nielsen, G. 2001. Organic compounds in indoor air- their relevance for perceived indoor air quality? Atmospheric Environment 35: 4407-4417.

Wood Buffalo Environmental Association (WBEA). 2006a. Human Exposure Monitoring Program: Part I: Background and Design Documentation. WBEA, Fort McMurray, AB.

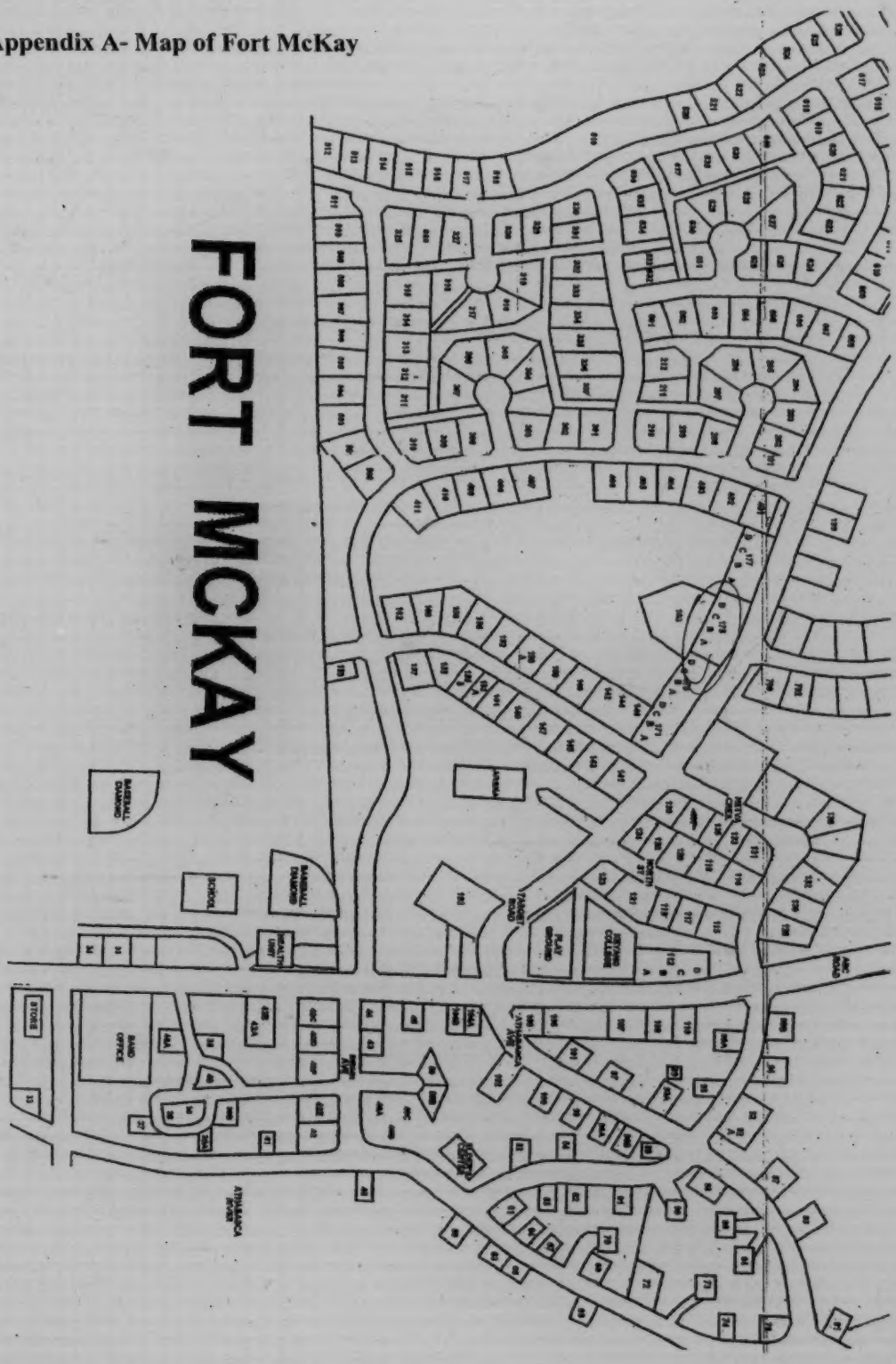
Wood Buffalo Environmental Association (WBEA). 2006b. Human Exposure Monitoring Program: Part II: Methods and Procedures. WBEA, Fort McMurray, AB.

World Health Organization (WHO), Regional Office for Europe. 1995. Methodology for assessment of exposure to environmental factors in application to epidemiological studies. The Science of the Total Environment 168: 93-100.

Zabiegala, B., Partyka, M. and Namiesnik, J. 2005. Employment of passive sampling in monitoring indoor air quality in selected residences in a Tri-city area in Poland. Toxicological and Environmental Chemistry 87(4): 529-541.
Zar, J. 1999. Biostatistical Analysis. Prentice Hall Inc., Upper Saddle River, NJ. 663 pp.

Zhu, J., Newhook, R., Marro, L., and Chan, C. 2005. Selected volatile organic compounds in residential air in the City of Ottawa, Canada. Environmental Science and Technology 39(11): 3964-3971.

Appendix A- Map of Fort McKay



About HEMP...

What is HEMP?
HEMP is a long term, on-going monitoring program designed to measure the level of selected air contaminants that individuals are exposed to in their everyday environments.

HEMP is operated by the Wood Buffalo Environmental Association and Alberta Health and Wellness on an on-going basis. The intent is to conduct the program on a continually rotating schedule, monitoring two communities per year in the Wood Buffalo Region.

Why is HEMP Important?
HEMP builds on existing data and allows for comparisons of selected air contaminants to be made over time. This is important because it allows for changes in air contaminants to be detected.

Program Details...

Objectives

- Monitor the levels of selected air contaminants in the community
- Examine the factors affecting human exposure to air contaminants
- Detect changes in air contaminants over time by comparing new data with data from previous years
- Examine the relationship between amounts of air contaminants in personal, indoor and outdoor air

Volunteer Info
HEMP volunteers will be asked to:

- Wear a set of passive and active air monitors for a continuous 7-day period;
- Allow additional air monitoring equipment to be set up in and outside of their homes for a continuous 7-day period; and
- Complete a short survey and time activity diary.

Contact Info...

If you have any questions, or are interested in learning more about the program, please contact us:

Project Coordinator:
Holly Fortier
Phone: (780) 828-2480
Email: holly27@telusplanet.net

You can also visit us on-line at:

www.wbea.org

W B E A

Appendix C- Information Letter

(ON LETTERHEAD)

VOLUNTEER INFORMATION LETTER

Project Title: HUMAN EXPOSURE MONITORING PROGRAM

Principal Investigator:
Dr. M. Gamal El-Din, Associate Professor, Department of Civil & Environmental Engineering, University of Alberta
Phone: (780) 492-5124
Mobile: (780) 231-3712

Graduate Students:
Garrett Hoeksema, Graduate Student, Department of Civil & Environmental Engineering, University of Alberta
Phone: (780) 492-8548

Laurie Cheperdak, Graduate Student, Department of Civil & Environmental Engineering, University of Alberta
Phone: (780) 492-8548

Purpose: The University of Alberta is performing an air quality monitoring study in order to assess the air quality in your region. Personal, indoor and outdoor air will be monitored in and around a small number of homes from this community to aid in understanding factors contributing to the human exposure of atmospheric pollution. If you choose to participate, monitoring equipment will be set up in and around your home for one week. As well, you will be required to wear some monitoring equipment for a one week period. The data collected will be used for the preparation of two graduate theses.

Background: Air quality within the Wood Buffalo region is typically good. Currently, approximately one million barrels of oil are produced from the oils sands every day, with projections estimating these numbers to quadruple in the next 15 years. This rapid growth in development activity and human population has raised awareness of air quality and quality of life in the region. The results of this study will show us how the industrial activities in the Municipality of Wood Buffalo affect the quality of the air you breathe. Volunteers are being recruited in your community by a random selection process. This is to ensure that the samples collected are representative of the population.

Benefits: There are no direct benefits for participating in this study for you. However, the results from this study will be used to inform researchers, government organizations (such as Alberta Environment and Alberta Health & Wellness) and the Wood Buffalo Environmental Association of the state of the air quality in your region.

Risks: Due to the wearing of battery-operated air sampling pumps, you **MUST NOT** wear the pumps while showering or bathing. To do so could result in an electric shock.

There may be some inconvenience and/or discomfort while wearing the monitoring equipment.

Confidentiality: All personal information collected will be coded to ensure confidentiality. Once collected, the data will be secured in the office of Dr. Gamal El-Din at the University of Alberta. Only the investigators will have access to your information. Your personal information will **NOT** be identified in any future publications or presentations.

Freedom to Withdraw: If you decline to continue or you wish to withdraw from the study at any point in time, your information will be removed from the study at your request.

Additional Contacts: If you have concerns about this study, you may contact Dr. James Miller, Chair of the Engineering Faculty Ethics Committee, at (780) 492-4443. Dr. Miller has no direct involvement with this project.

Appendix D- Floor Plan

Floor Plan

Participant ID #:

Date:

Instructions: Draw a map of the floor plan of the home so that you can record your choice of location for the indoor and outdoor samplers. The map should be a simple floor plan that indicates the location of the street, the entry and inside doors, windows, walls, and the location for the indoor and outdoor samplers. Label each of the rooms clearly. Indicate any possible sources of contamination.

Appendix E- Appropriate Positioning of Sampling Stands

Indoor and Outdoor Stands

- Sampling height should be around 1-1.5 meters above ground level. Use of the sampling stands will assure a consistent height during exposure is maintained.

Indoor Stands

- Place the stands a minimum of 2 meters away from exterior doors, windows and ventilation registers.
- Avoid placement along exterior walls.
- Areas with noticeable drafts should be avoided (i.e. near open windows, etc.)
- Locations with high traffic should be avoided.
- Areas that are directly impacted by indoor sources (i.e. gas stoves, fireplaces, etc.) should be avoided.

Outdoor Stands

- Maintain a distance of at least 1 meter from trees or shrubs, and 5 meters from any form of air exhaust (i.e. air conditioning, dryer vents, etc.), and/or driveway.
- Avoid areas of high humidity, as this can adversely impact results, causing a reduction of saturation capacity for the charcoal badges.

Appendix F- PEM Do's and Don'ts

Volunteer information sheet
Tips about your air monitors and participation

PLEASE:

- Explain the fragile and breakable air monitors to young children and others that might be tempted to touch or accidentally damage them.
- If you must handle the air monitors, please do so with care at all times. Always use the clips for handling the air monitors.
- Wear the air monitors as close to your breathing area as possible, preferably using the adjustable sampling necklace provided by the field teams.
- Remember to wear the air monitors on the outside your jacket, if you are wearing one. You do not want to restrict natural airflow across the face of the monitors.
- Wear the sampler at all times, except while sleeping, showering, or participating in activities which wearing the monitors would be harmful to yourself or may damage the monitors. In these circumstances, please simply keep the monitors as close to you as possible.
- Remember to complete your time activity diary and your survey during the one-week period.
- Please remember to change your personal pump batteries when requested to do so.
- Please check that the personal, indoor, and outdoor pumps are on at least once per day.
- Do not hesitate to contact the project coordinator or ask the field teams if you have problems, questions, or concerns.

PLEASE DON'T:

- Touch the face of the sampler. They are easily damaged and may void results.
- Get the sampler wet. When taking a shower place sampler in the bathroom on a countertop. If it is raining outside, please try to keep it relatively dry, while at the same time, not restricting the flow of air across the face of the sampler.
- Spray water on outdoor air monitors. Although there is a rain shield to protect the monitors from rain and snow, sprinkler systems may still interfere with outdoor equipment.
- Play contact sports (e.g., hockey, football, soccer, baseball) with the air monitors on. Please leave them on the player's bench or vicinity close to your activity to avoid damage.
- Sleep with the air monitoring equipment on. Please remove and place in a vicinity as close as possible to your presence such as a bedside table or dresser. You may be disturbed by the noise of the pump in which case placing it in the hallway or another room would be appropriate.
- Wear silk shirts if using the metal clips as an alternative to the sampling necklace as the clips may cause holes in delicate fabrics.

Appendix G-Volatile Organic Compound (VOC) Sampling Protocol (WBEA 2006b)

A. Set-Up of VOC Air Monitors:

1. Each VOC monitor is packaged in a 3M aluminium can. The original shipping container must be used to send the exposed monitor to the laboratory for analysis. Ensure that the outside label corresponds to the type of monitor that you are intending to open.

2. Remove the plastic lid from the can. There should be four removable labels under the tab of the can. Ensure that all four labels as well as the label affixed to the side and lid of the can are identical.

3. Open the can carefully and remove the air monitor from the can.
IMPORTANT NOTE: *Do not touch the white face or remove the plastic ring when deploying. If the ring tab snaps off while attempting to open the container, you may be able to carefully use something to assist in removing the lid. As a last resort, use the can opener provided in the emergency kit. This will destroy the container and will require you to use parafilm to reseal the exposed sampler.*

4. **Important step:** Affix one of the labels to the **back of the VOC sampler** and one to the field data log sheet in the appropriate space provided. Place the remaining two labels back into the container (the laboratory will require the remaining labels). *Note: Please leave the plastic closure cap and the plastic piece of tube in the container.*

5. The following should be recorded on the field data log sheet: participant number, site description, date and time (military or indicate am/pm) of sample initiation, and relevant comments as deemed necessary.

6. Ensure that the sampler is intact and the clip is operable. If the clip is broken or the permeation barrier of the sampler is damaged, it is advised that you do not use this sampler or at the very least, record this information on the log sheet.
IMPORTANT NOTE: *If the clip has received damaged, please note this on the log sheet. You may be able to still use the monitor as a blank, by switching it with the monitor located in the blank set of monitors, or you may be able to repair the monitor using items from the emergency kit.*

7. Attach the air monitor to the personal sampler necklace, the indoor stand, or the outdoor stand.

B. Retrieval of VOC Air Monitors:

1. **Important step:** After the sampling period has ended, **remove the plastic ring and white film** from the face of the sampler.
IMPORTANT NOTE*: If you are having trouble removing the plastic ring, you may use something (e.g., coin or key) to carefully pry it off.*

2. Take the **plastic closure cap** from the container and firmly snap it onto the face of the sampler gently using your thumbs, starting at one end of the cap and gently working your thumbs around the sides, meeting at the top.

IMPORTANT NOTE*: You should not have to use excessive force and it will be easiest to have one part of the closure cap fitted into place before continuing around the perimeter. You should hear evident clicking sounds when it is properly sealed.*

3. Ensure that the two port plugs of the closure cap are firmly seated.

4. Turn the metal clip to one side and return the monitor to the appropriate can and seal with plastic lid provided. Ensure that the labels on the sampler and the container are identical. Seal the lid to the can with parafilm tape.

5. Record the date and time of sample termination on the data log sheet. Record any relevant comments such as damage to the air monitor, discoloration on the face of the air monitor, movement of the sampling stand, or relevant participant comments (e.g., Participant indicated that they spilled something on the face of the sampler).

6. Exposed monitors are to be collected at a central location and shipment is made to the laboratory.

C. Preparation of VOC Blank:

IMPORTANT NOTE: *Passive monitoring field blanks should be completed during the set-up stage and should be completed for every participant.*

1. Follow all steps above, except for step 7 (i.e., do not expose the air monitor for any relevant length of time) and immediately continue to the retrieval steps as if the monitor was exposed. It is not necessary to record the time of exposure, as the "blank" monitors will not be exposed for any relevant length of time. It is important the blank monitors are handled and transported in the same way as the "exposed" monitors.

2. Be certain to parafilm blank VOC air monitor as soon as they are returned to the containers

Appendix H- Passive Log Sheet

Wood Buffalo Environmental Association Human Exposure Monitoring Program
NO_2, SO_2, O_3, and VOC FIELD DATA LOG SHEET

Participant ID #: _____ Start Date: _____ Received by: _____

Submitted by Field Team Members: _____ End Date: _____

		NO_2	SO_2	O_3	VOCs
PERSONAL	Sampler ID #:				
	Start Time:				
	End Time:				
	Comments:				
INDOOR	Sampler ID #:				
	Start Time:				
	End Time:				
	Comments:				
OUTDOOR	Sampler ID #:				
	Start Time:				
	End Time:				
	Comments:				
BLANK	Sampler ID #:				
	Comments:				

Appendix I- Time Activity Diary Instructions

TIME ACTIVITY DIARY INSTRUCTIONS

The Time Activity Diary is designed to enable you to estimate the amount of time you spend in various locations while wearing the personal exposure monitors. There are seven locations of interest:

1) **Indoors at home** – includes any activities done inside your place of residence (e.g., housework, office work, eating, sleeping, watching television, using computer, etc.).

2) **Outdoors at home** – includes any activities done outside your place of residence (e.g., cutting grass, shovelling snow, gardening, painting deck, sunbathing, etc.).

3) **Indoors at work** – includes any activities done inside your place of work or school (**Note:** If you work out of your home, please use the "Indoors/Outdoors at home" category to record this information).

4) **Outdoors at work** – includes any activities done outside your place of work or school.

5) **Indoors Elsewhere** – includes any activities done inside other locations (e.g., grocery shopping, hairdresser, bank, indoor recreational activities, theatre, restaurant/pub, etc.).

6) **Outdoors Elsewhere** – includes any activities done outside other locations (e.g., outdoor recreational activities, picnic, walk dog, camping, waiting for bus, etc.)

7) **Travelling** – includes any activity involving the operation of or transport in a motorized vehicle (e.g., driving to work/school, riding a bus, truck driving, snowmobiling, motorcycling, etc.).

Ideally, it would be more accurate to keep your diary sheets with you throughout the day, periodically recording your activities. Please attempt to be as accurate as possible, ensuring that if you are moving from one category (i.e., outdoors at home) to another (i.e., indoors at home) to make a single entry for each location. Also, be sure that if you are changing locations from home to work/school to indicate how you arrived at this new location (i.e., walking = outdoors elsewhere, car = travelling).

SEE EXAMPLE ON OTHER SIDE.

For example, the participant below received their diary at 6:00pm:

Entry #1) From 6:00-8:00pm they were outfitted with their monitors, filled in some of their questionnaire, ate supper, and watched television → check indoors at home

Entry #2) From 8:00-8:10pm they drove to their friend's house by car → travelling

Entry #3) From 8:10-8:30pm they waited inside their friend's house →indoors elsewhere

Entry #4) From 8:30-8:50pm they walked to the movie theatre →outdoors elsewhere

Entry #5) From 8:50-11:00pm they watched a movie → indoors elsewhere

Entry #6) From 11:00-11:20pm they walked back to their friend's house → outdoors elsewhere

Entry #7) From 11:20-11:30pm they drove back to their house → travelling

Entry #8) From 11:30pm-7:40am they got ready for bed, slept, had breakfast and got ready for work → indoors at home

Entry #9) From 7:40-7:50am they went out the front door to the end of the driveway and waited for their ride → outdoors at home

Entry #10) From 7:50-8:30am they rode in a car (or bus) to work (or school) → travelling

Entry #11) and Entry #12) From 8:30am-12:30pm they worked about equal time indoors and outdoors → **Note:** This requires two separate entries (indoors at work and outdoors at work) -- please try and estimate the **amount of time spent in each location**. The actual time of day is not as important as the amount of time in each location.

	TIME	LOCATION (check only one location per row)			
1	6:00-8:00pm	☒ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☐ Travelling
2	8:00-8:10pm	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☒ Travelling
3	8:10-8:30pm	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☒ Indoors Elsewhere ☐ Outdoors Elsewhere	☐ Travelling
4	8:30-8:50pm	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☒ Outdoors Elsewhere	☐ Travelling
5	8:50-11:00pm	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☒ Indoors Elsewhere ☐ Outdoors Elsewhere	☐ Travelling
6	11:00-11:20pm	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☒ Outdoors Elsewhere	☐ Travelling
7	11:20-11:30pm	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☒ Travelling
8	11:30pm-7:40am	☒ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☐ Travelling
9	7:40-7:50am	☐ Indoors at home ☒ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☐ Travelling
10	7:50-8:30am	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☒ Travelling
11	8:30-10:30am	☐ Indoors at home ☐ Outdoors at home	☒ Indoors at work ☐ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☐ Travelling
12	10:30am-12:30pm	☐ Indoors at home ☐ Outdoors at home	☐ Indoors at work ☒ Outdoors at work	☐ Indoors Elsewhere ☐ Outdoors Elsewhere	☐ Travelling

Appendix J- Consent Forms

(ON LETTERHEAD)
CONSENT TEMPLATE

Part 1 (to be completed by the Principal Investigator)

Title of Project: **HUMAN EXPOSURE MONITORING PROGRAM**

Principal Investigator(s): Dr. Mohamed Gamal El-Din, Civil and Environmental Engineering Department, University of Alberta
Ph.: (780)492-5124

Co-Investigator(s): Mr. Garrett Hoeksema, Graduate Student, Civil and Environmental Engineering Department, University of Alberta
Ph.: (780)492-8548
Ms. Laurie Cheperdak, Graduate Student, Civil and Environmental Engineering Department, University of Alberta
Ph.: (780)492-8548

Part 2 (to be completed by the research participant)

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate, or to withdraw from the study at any time, without consequence, and that your information will be withdrawn at your request?	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your information?	Yes	No

This study was explained to me by: _____

I agree to take part in this study:

_____	_____	_____
Signature of Research Participant	Date	Witness
_____		_____
Printed Name		Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

_____	_____
Signature of Investigator or Designee	Date

Human Exposure

Human Exposure Monitoring Program – Volunteer Consent Form

I understand that the Wood Buffalo Environmental Association is engaged in an ongoing human air monitoring program of people's exposure to certain airborne substances. I understand that this program is being conducted in order to help measure levels of exposure to selected substances, and is limited to the purpose stated.

I do hereby freely consent to participate in the WBEA Human Exposure Monitoring Program and agree to provide the following data:

- answers to questions related to environmental exposure through work and living conditions;
- air monitoring data collected through the use of a personal exposure monitor;
- air monitoring data collected inside and outside my home through the use of fixed location air monitors; and
- a record of my time spent in various locations during my participation.

I understand and agree that:

- an agent of the study will distribute the questionnaires, will collect the resulting information; and will set up the monitoring equipment in my home
- the Wood Buffalo Environmental Association may use and disclose the information thus obtained to meet the objectives of the program, so long as my name or other identifying features are never referred to in any way and that information is only published in aggregate form;
- there is no obligation to be provided with any individual results from my participation in this study.

It has been explained to me that there are no significant risks or direct benefits to me from participation in this study. I understand that I am free to withdraw at any time, and withdrawing from the study will not have any adverse effect on my access to health care services. I further understand that while participating in this study I will be free to ask any questions concerning the study.

☐ I have read and agree with the above.

**Please note, due to the limited number of volunteers required, entry submission will not guarantee or imply that you will beselected for the program.

Human Exposure

Human Exposure Monitoring Program - Volunteer Participation Registration Form

1. Name _____
2. Phone Numbers: Home: _____ Work: _____
3. Age of Volunteer (must be 18 years or over at start date): _____
4. Gender: Male_____ Female _____
5. a) What type of work do you do? (Describe your occupation; job title)
   _____

   b) Where do you work? (Describe location and/or company name)
   _____
6. Home Address (complete home address including postal; legal land description may be useful if located in rural area
   _____
   _____

   ❑ Fort McMurray ❑ Fort McMurray First Nation Reserve ❑ Fort Chipewyan ❑ Other _____
7. Even though smokers and smoking households are not excluded from participating, does any person currently smoke in your home on a regular basis? ❑ Yes ❑ No
8. Dates unavailable to participate (i.e., vacation, traveling out of study area): _____
9. How did you hear about the study (newspaper, radio, tradeshow, website, word of mouth): _____

Appendix K- Raw Analytical Results

Monitor	Participant ID	Location	Hexane (ug/m^3)	3-Methylhexane (ug/m^3)	Heptane (ug/m^3)	Octane (ug/m^3)	Nonane (ug/m^3)	Decane (ug/m^3)
VOC 6037	1201	Indoor	1.30	0.00	0.00	0.00	0.00	0.00
VOC 6058	1202	Indoor	1.30	0.77	2.37	0.84	1.21	0.71
VOC 6005	1203	Indoor	0.84	0.00	0.57	0.00	0.00	0.77
VOC 6020	1204	Indoor	0.74	2.01	3.76	0.00	0.00	0.00
VOC 6021	1204	Indoor	0.79	2.01	3.71	0.00	0.00	0.00
VOC 6030	1205	Indoor	1.63	0.51	1.80	0.56	0.00	0.00
VOC 6015	1206	Indoor	1.16	0.00	0.00	0.90	0.79	0.64
VOC 6018	1207	Indoor	3.81	0.72	0.00	0.73	1.33	0.90
VOC 6032	1208	Indoor	1.67	0.98	2.99	1.68	1.33	1.16
VOC 6011	1208	Indoor	1.81	1.03	0.00	1.68	1.21	1.16
VOC 6046	1209	Indoor	4.42	0.62	1.85	0.95	1.51	1.16
VOC 6059	1210	Indoor	0.93	0.00	0.00	0.90	0.91	0.00
VOC 6076	1211	Indoor	9.53	1.65	3.40	1.23	0.00	0.71
VOC 6113	1212	Indoor	0.56	0.00	0.00	0.00	0.00	0.00
VOC 6108	1212	Indoor	0.56	0.00	0.88	0.00	0.00	0.00
VOC 6110	1213	Indoor	0.98	0.00	0.00	0.91	0.00	0.98
VOC 6109	1214	Indoor	0.74	0.00	1.03	0.56	0.00	0.00
VOC 6066	1215	Indoor	1.12	12.31	15.86	29.87	7.98	0.71
VOC 6092	1216	Indoor	149.46	41.66	55.71	51.08	25.41	2.58
VOC 6072	1217	Indoor	1.07	0.51	1.75	0.84	0.67	0.00
VOC 6073	1217	Indoor	1.16	0.57	1.85	0.90	0.73	0.00
VOC 6118	1218	Indoor	1.14	4.33	10.15	2.15	1.06	0.00
VOC 6098	1219	Indoor	1.77	0.88	1.13	0.67	0.00	0.97
VOC 6162	1220	Indoor	0.65	0.00	0.82	0.95	0.00	0.00
VOC 6123	1221	Indoor	1.02	0.00	0.00	0.73	0.00	0.71
VOC 6179	1222	Indoor	1.95	1.18	1.08	0.95	4.23	20.55
VOC 6181	1222	Indoor	2.00	1.24	1.13	1.01	5.32	24.22
VOC 6061	1223	Indoor	0.79	0.00	1.54	1.51	5.87	14.82
VOC 6172	1224	Indoor	11.86	5.30	5.05	2.24	0.00	17.20
VOC 6156	1225	Indoor	1.86	0.00	1.13	1.01	5.38	20.42
VOC 6183	1226	Indoor	0.93	0.00	0.72	0.62	0.00	0.84
VOC 6150	1227	Indoor	0.79	0.00	0.00	0.56	0.00	0.00
VOC 6167	1228	Indoor	1.35	0.00	0.00	0.67	0.00	0.00
VOC 6182	1229	Indoor	1.44	0.00	1.85	1.57	3.63	3.41
VOC 6177	1230	Indoor	23.72	8.39	13.18	28.92	16.76	7.54
VOC 6139	1231	Indoor	9.44	3.19	4.99	2.13	0.00	1.29
VOC 6131	1232	Indoor	1.77	1.39	4.22	3.19	0.00	0.71
VOC 6129	1233	Indoor	8.88	3.76	5.51	2.80	0.00	2.90
VOC 6141	1234	Indoor	6.46	2.21	3.09	1.40	0.00	0.90
VOC 6169	1235	Indoor	1.40	0.57	0.00	1.17	0.91	1.10

Monitor	Participant ID	Location	Hexane (ug/m^3)	3-Methylhexane (ug/m^3)	Heptane (ug/m^3)	Octane (ug/m^3)	Nonane (ug/m^3)	Decane (ug/m^3)
VOC 6036	1201	Outdoor	0.84	0.00	0.00	0.00	0.00	0.00
VOC 6049	1202	Outdoor	0.79	0.00	0.00	0.00	0.00	0.00
VOC 6013	1203	Outdoor	0.98	0.00	0.51	0.00	0.00	0.00
VOC 6014	1204	Outdoor	0.70	0.00	0.00	0.00	0.00	0.00
VOC 6007	1205	Outdoor	1.21	0.00	0.00	0.00	0.00	0.00
VOC 6025	1206	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6012	1207	Outdoor	0.51	0.00	0.51	0.00	0.00	0.00
VOC 6060	1207	Outdoor	0.56	0.00	0.57	0.00	0.00	0.00
VOC 6056	1208	Outdoor	0.56	0.00	0.82	0.67	0.85	0.00
VOC 6004	1209	Outdoor	0.79	0.00	0.77	0.56	0.79	0.00
VOC 6016	1210	Outdoor	0.56	0.00	0.57	0.00	0.00	0.00
VOC 6041	1210	Outdoor	0.56	0.00	0.62	0.00	0.00	0.00
VOC 6104	1211	Outdoor	0.00	0.00	0.57	0.00	0.00	0.00
VOC 6116	1212	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6075	1213	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6080	1214	Outdoor	0.00	0.00	0.51	0.00	0.00	0.00
VOC 6094	1215	Outdoor	0.00	0.00	0.57	0.00	0.00	0.00
VOC 6062	1216	Outdoor	0.00	0.00	0.67	0.00	0.00	0.00
VOC 6070	1217	Outdoor	0.74	0.00	0.98	0.67	0.00	0.00
VOC 6079	1218	Outdoor	0.65	0.00	0.96	0.65	0.00	0.00
VOC 6103	1218	Outdoor	0.71	0.00	1.02	0.72	0.71	0.00
VOC 6071	1219	Outdoor	0.60	0.00	0.00	0.00	0.00	0.00
VOC 6146	1220	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6121	1221	Outdoor	0.47	0.00	0.00	0.00	0.00	0.00
VOC 6151	1222	Outdoor	0.60	0.00	0.00	0.00	0.00	0.00
VOC 6089	1223	Outdoor	0.47	0.00	0.00	0.00	0.00	0.00
VOC 6091	1223	Outdoor	0.47	0.00	0.00	0.00	0.00	0.00
VOC 6153	1224	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6128	1225	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6180	1226	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6124	1226	Outdoor	0.47	0.00	0.00	0.00	0.00	0.00
VOC 6147	1227	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6138	1228	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6152	1229	Outdoor	0.79	0.51	0.62	0.00	0.00	0.00
VOC 6142	1230	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6130	1231	Outdoor	1.53	1.29	3.81	2.91	1.03	0.00
VOC 6143	1232	Outdoor	1.30	1.13	3.66	2.80	0.00	0.00
VOC 6186	1233	Outdoor	1.30	1.18	4.12	3.36	1.15	0.00
VOC 6125	1234	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6148	1235	Outdoor	0.00	0.00	0.00	0.00	0.00	0.00

Monitor	Participant ID	Location	Hexane (ug/m^3)	3-Methylhexane (ug/m^3)	Heptane (ug/m^3)	Octane (ug/m^3)	Nonane (ug/m^3)	Decane (ug/m^3)
VOC 6038	1201	Personal	2.51	0.82	1.91	0.56	0.00	0.00
VOC 6048	1202	Personal	1.07	0.62	1.96	0.67	0.85	0.00
VOC 6006	1203	Personal	1.49	0.00	0.57	0.00	0.00	0.00
VOC 6043	1204	Personal	0.98	1.70	3.09	0.00	0.73	0.00
VOC 6051	1205	Personal	1.30	0.00	1.29	0.00	0.00	0.00
VOC 6022	1205	Personal	1.35	0.00	1.29	0.00	0.00	0.00
VOC 6017	1206	Personal	1.53	0.00	0.00	0.56	0.60	1.03
VOC 6029	1207	Personal	3.30	0.72	1.54	0.78	1.03	0.97
VOC 6053	1208	Personal	1.72	0.98	2.68	1.45	1.21	1.10
VOC 6027	1209	Personal	4.09	0.93	2.47	1.06	1.33	1.48
VOC 6044	1210	Personal	1.35	0.77	0.00	1.57	1.03	0.71
VOC 6086	1211	Personal	10.88	2.32	3.66	1.29	0.85	0.71
VOC 6111	1212	Personal	0.60	0.00	0.00	0.00	0.00	0.00
VOC 6078	1213	Personal	3.47	0.00	0.90	0.65	0.00	0.00
VOC 6114	1213	Personal	3.36	0.00	0.90	0.65	0.00	0.00
VOC 6106	1214	Personal	0.84	0.00	1.03	0.62	0.00	0.00
VOC 6064	1215	Personal	1.12	11.95	15.24	28.14	7.68	0.64
VOC 6090	1216	Personal	133.74	37.59	53.76	40.06	18.69	2.38
VOC 6099	1217	Personal	0.84	0.00	1.44	0.84	0.00	0.00
VOC 6088	1218	Personal	1.25	3.36	7.75	1.96	1.13	0.98
VOC 6105	1218	Personal	1.25	3.36	7.69	1.83	1.13	0.90
VOC 6096	1219	Personal	1.58	0.82	1.03	0.67	0.00	0.84
VOC 6097	1219	Personal	1.58	0.82	1.03	0.62	0.00	0.90
VOC 6095	1220	Personal	0.65	0.00	0.62	0.62	0.00	0.00
VOC 6171	1221	Personal	1.30	0.00	0.00	0.73	0.00	0.77
VOC 6133	1222	Personal	1.86	1.29	1.39	0.90	3.69	17.46
VOC 6063	1223	Personal	0.84	0.00	1.49	1.40	4.17	11.08
VOC 6134	1224	Personal	8.23	4.12	5.56	4.70	3.99	11.66
VOC 6173	1225	Personal	2.56	0.67	1.29	1.06	5.57	21.19
VOC 6135	1226	Personal	0.88	0.00	0.72	0.62	0.00	0.00
VOC 6168	1226	Personal	0.93	0.00	0.77	0.62	0.00	0.84
VOC 6163	1227	Personal	0.93	0.67	1.80	0.62	0.79	0.71
VOC 6164	1228	Personal	0.84	0.00	0.93	0.62	0.00	0.00
VOC 6132	1229	Personal	2.93	0.93	2.11	1.68	3.15	4.77
VOC 6170	1230	Personal	2.46	0.98	1.08	0.67	0.00	1.03
VOC 6178	1231	Personal	6.56	2.32	3.86	2.07	1.09	2.58
VOC 6154	1232	Personal	1.40	1.03	3.19	2.35	1.21	0.64
VOC 6198	1233	Personal	14.37	4.53	9.47	4.14	2.54	2.96
VOC 6144	1234	Personal	4.46	4.48	6.49	1.45	1.03	1.16
VOC 6145	1235	Personal	13.67	0.72	0.00	4.92	2.48	3.74

Appendix L- Raw Blank Results

Monitor	Participant ID	Location	Hexane (ug/m^3)	3-Methylhexane (ug/m^3)	Heptane (ug/m^3)	Octane (ug/m^3)	Nonane (ug/m^3)	Decane (ug/m^3)
VOC 6054	1201	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6047	1202	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6009	1203	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6028	1204	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6026	1205	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6040	1206	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6039	1207	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6052	1208	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6033	1209	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6055	1210	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6084	1211	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6107	1212	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6082	1213	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6112	1214	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6087	1215	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6083	1216	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6102	1217	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6119	1218	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6101	1219	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6149	1220	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6126	1221	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6165	1222	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6077	1223	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6175	1224	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6174	1225	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6158	1226	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6137	1227	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6166	1228	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6136	1229	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6157	1230	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6184	1231	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6140	1232	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6201	1233	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6176	1234	Blank	0.00	0.00	0.00	0.00	0.00	0.00
VOC 6127	1235	Blank	0.00	0.00	0.00	0.00	0.00	0.00

Appendix M- Summary Sampling Precision (COV, %)

Table M1. Indoor sampling precision (COV, %)

Replicates	Volatile Organic Compound (VOC)					
	Hexane	Heptane	Octane	Nonane	Decane	3-Methylhexane
1	4	1				0
2	6		0	7	0	4
3						
4	6	4	5	6	0	7
5	2	3	4	16	12	3
Mean	3	3	3	10	4	3
Median	4	3	4	7	0	3
Minimum	0	1	0	6	0	0
Maximum	6	4	5	16	12	7

*Note: Based on 7 day exposure

Table M2. Outdoor sampling precision (COV, %)

Replicates	Volatile Organic Compound (VOC)					
	Hexane	Heptane	Octane	Nonane	Decane	3-Methylhexane
1	6	7				
2	0	6				
3	6	4				
4	3					
5						
Mean	3	6				
Median	3	6				
Minimum	0	4				
Maximum	6	7				

* Note: Based on 7 day exposure

Table M3. Personal sampling precision (COV, %)

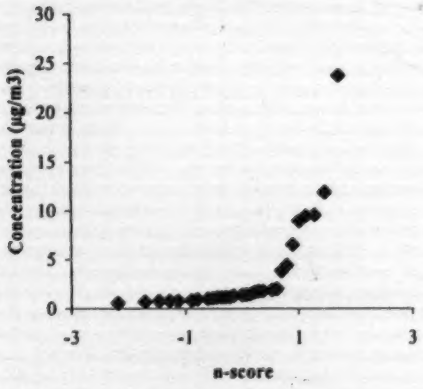
Replicates	Volatile Organic Compound (VOC)					
	Hexane	Heptane	Octane	Nonane	Decane	3-Methylhexane
1	2	0				
2	2	0	0			
3	0	1	0			
4	0	0	6			
5	4	5	0			
Mean	2	1	2			
Median	2	0	0			
Minimum	0	0	0			
Maximum	4	5	6			

*** Note: Based on 7 day exposure**

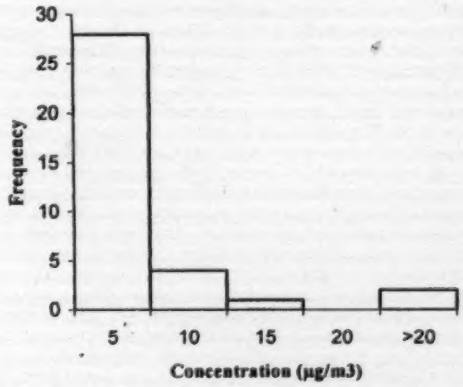
Only samplers in which both had levels above the MDL were used in the COV calculations.

Appendix N-Distribution Histograms and Probability Plots

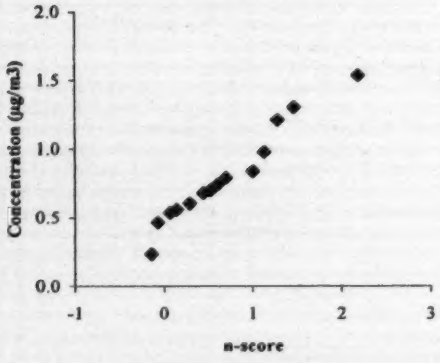
Normal Probability Plot- Hex (In)



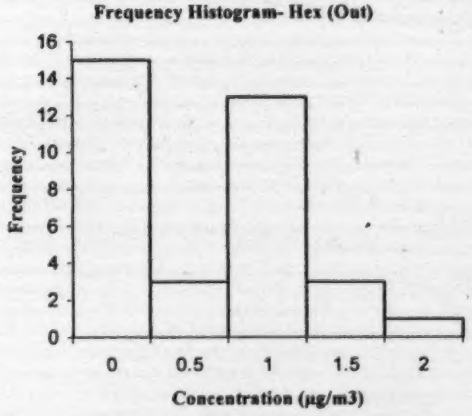
Frequency Histogram- Hex (In)



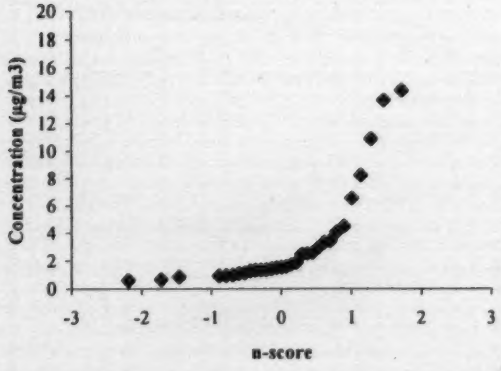
Normal Probability Plot- Hex (Out)



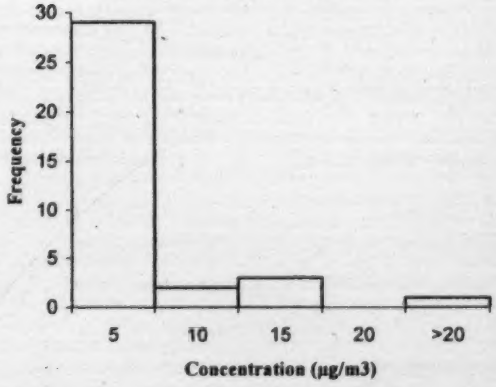
Frequency Histogram- Hex (Out)

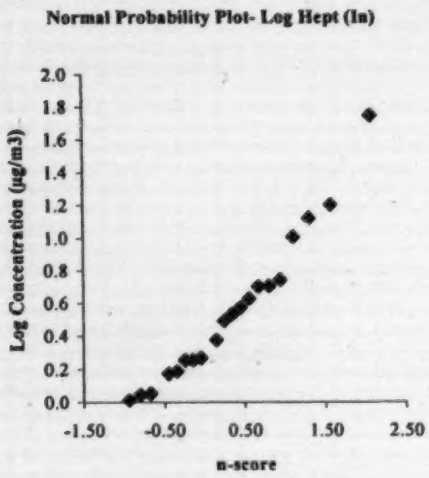


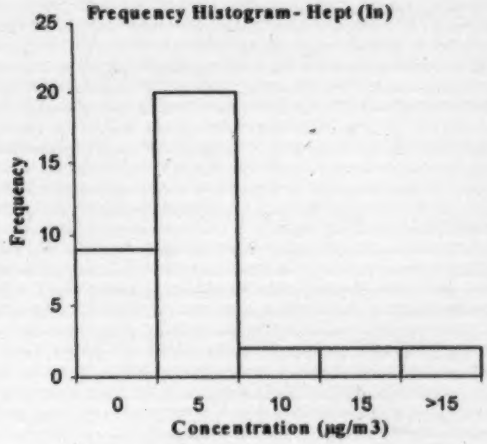
Normal Probability Plot- Hex (Personal)

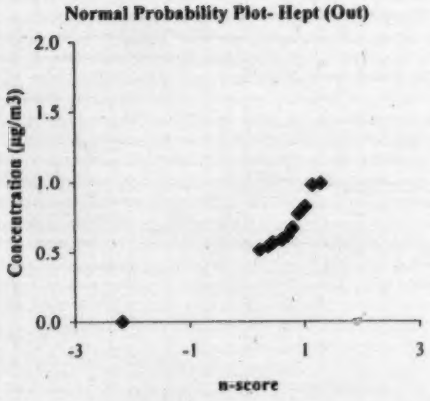


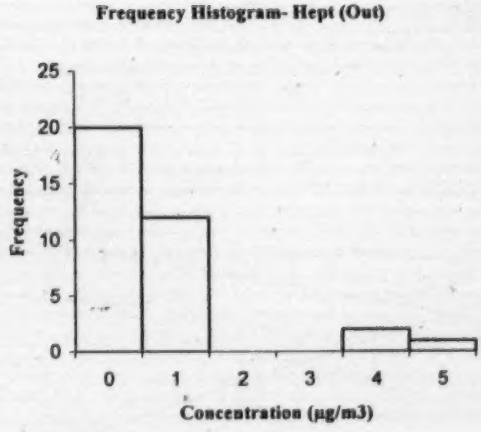
Frequency Histogram- Hex (Personal)

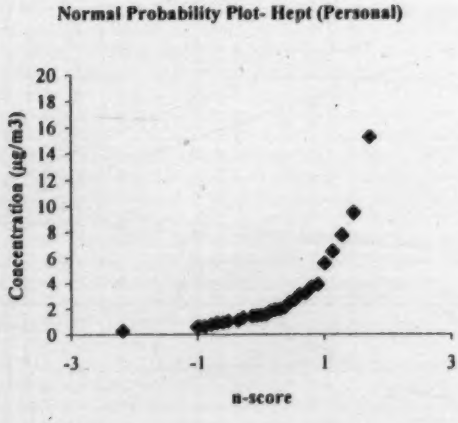



Normal Probability Plot- Log Hept (In)
Log Concentration (µg/m3)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-1.50
-0.50
0.50
1.50
2.50
n-score


Frequency Histogram- Hept (In)
Frequency
25
20
15
10
5
0
0
5
10
15
>15
Concentration (µg/m3)


Normal Probability Plot- Hept (Out)
Concentration (µg/m3)
2.0
1.5
1.0
0.5
0.0
-3
-1
1
3
n-score


Frequency Histogram- Hept (Out)
Frequency
25
20
15
10
5
0
0
1
2
3
4
5
Concentration (µg/m3)


Normal Probability Plot- Hept (Personal)
Concentration (µg/m3)
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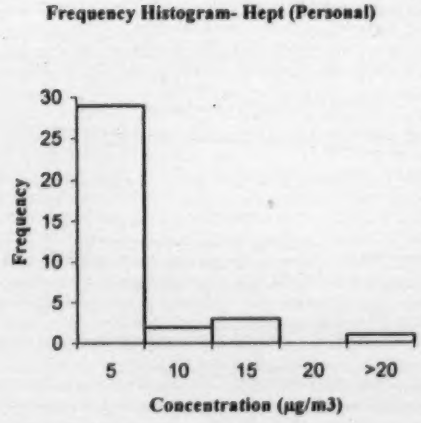
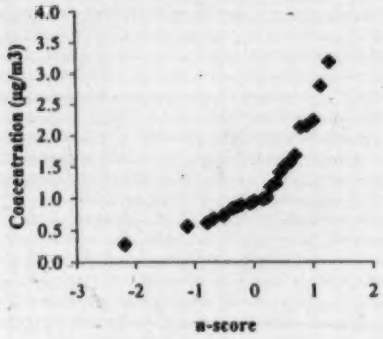
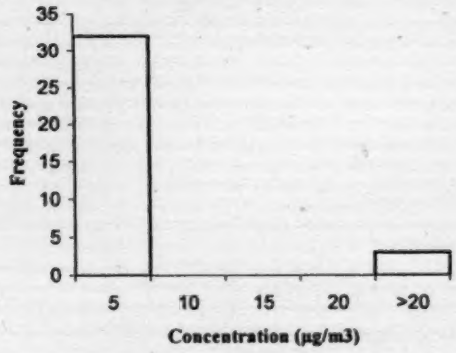
18
16
14
12
10
8
6
4
2
0
-3
-1
1
3
n-score


Frequency Histogram- Hept (Personal)
Frequency
30
25
20
15
10
5
0
5
10
15
20
>20
Concentration (µg/m3)

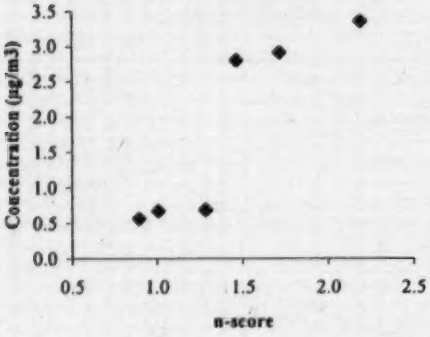
Normal Probability Plot- Oct (In)



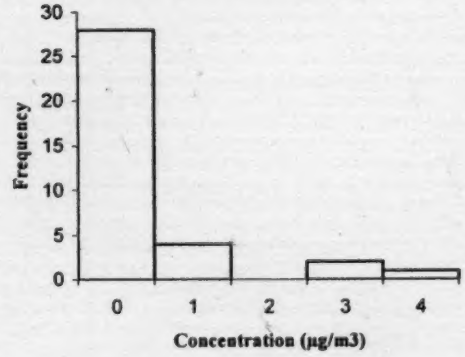
Frequency Histogram- Oct (In)



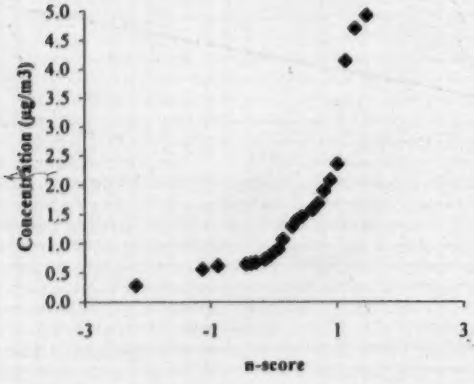
Normal Probability Plot- Oct (Out)



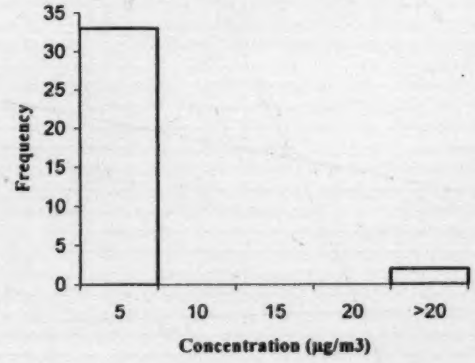
Frequency Histogram- Oct (Out)

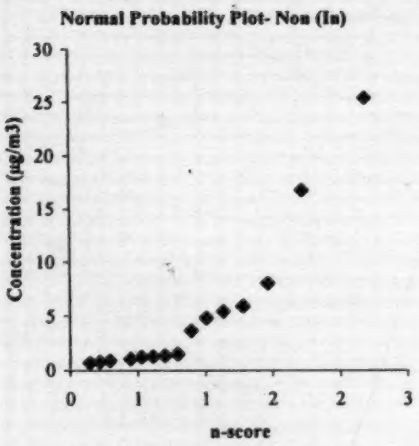


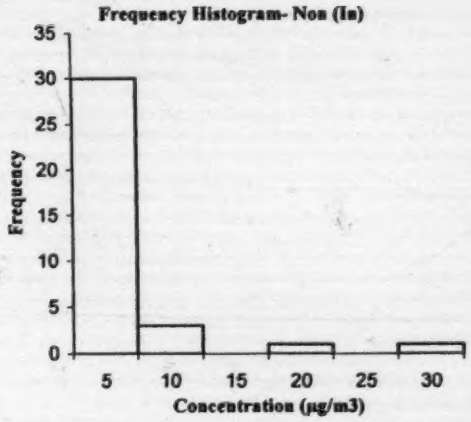
Normal Probability Plot- Oct (Personal)

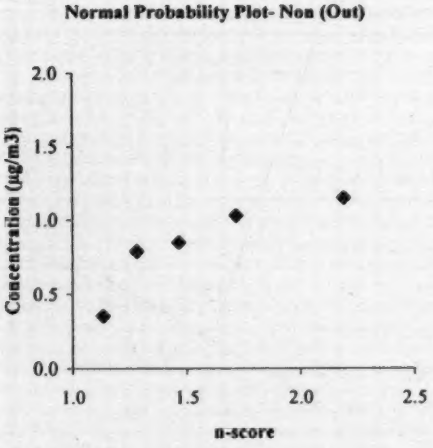


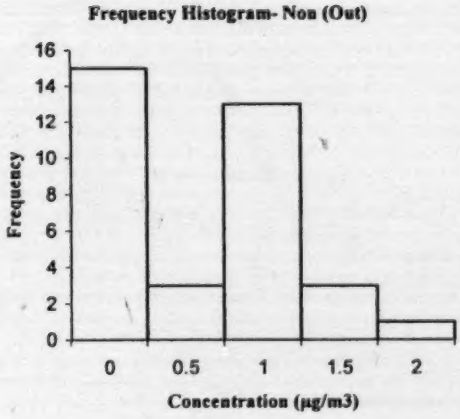
Frequency Histogram- Oct (Personal)

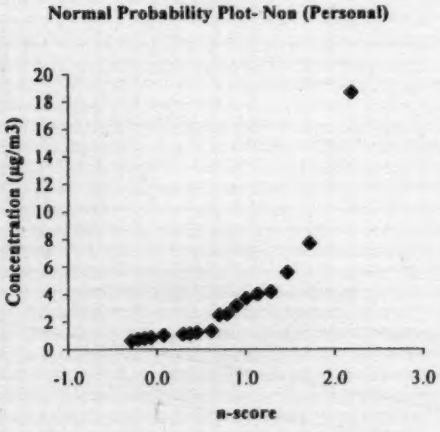


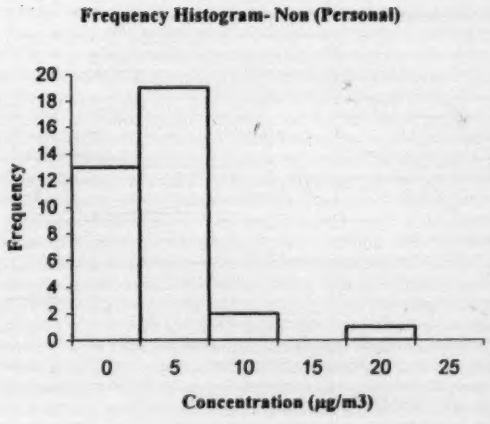

Normal Probability Plot- Non (In)
Concentration (µg/m3)
n-score


Frequency Histogram- Non (In)
Frequency
Concentration (µg/m3)

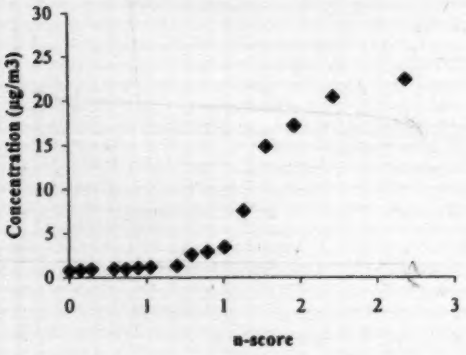

Normal Probability Plot- Non (Out)
Concentration (µg/m3)
n-score


Frequency Histogram- Non (Out)
Frequency
Concentration (µg/m3)

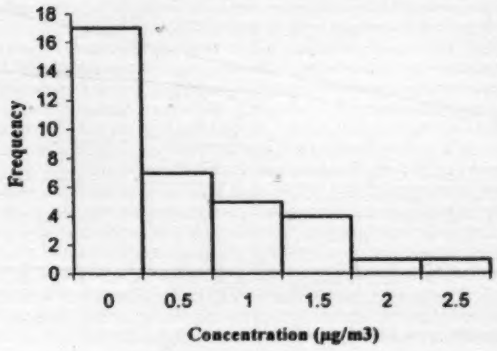

Normal Probability Plot- Non (Personal)
Concentration (µg/m3)
n-score


Frequency Histogram- Non (Personal)
Frequency
Concentration (µg/m3)

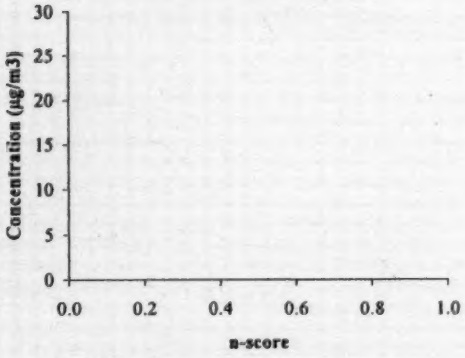
Normal Probability Plot- Dec (In)



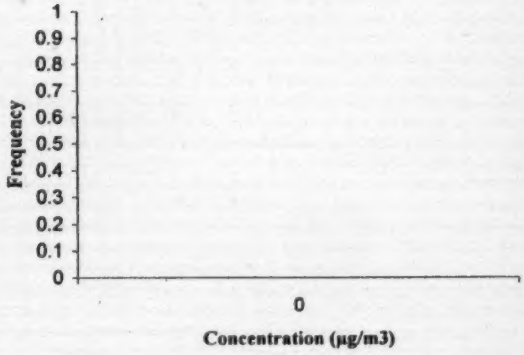
Frequency Histogram- Dec (In)



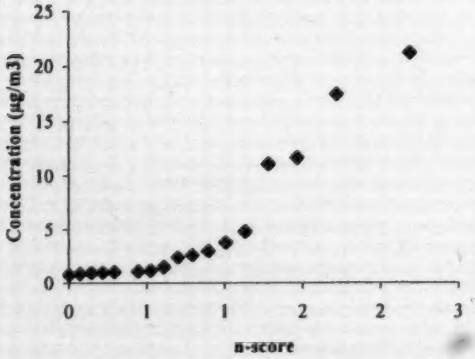
Normal Probability Plot- Dec (Out)



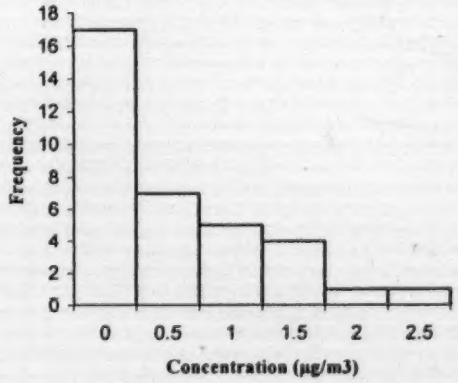
Frequency Histogram- Dec (Out)



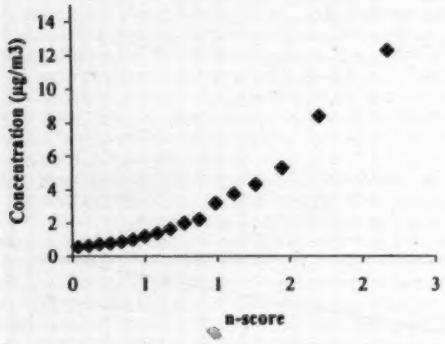
Normal Probability Plot- Dec (Personal)



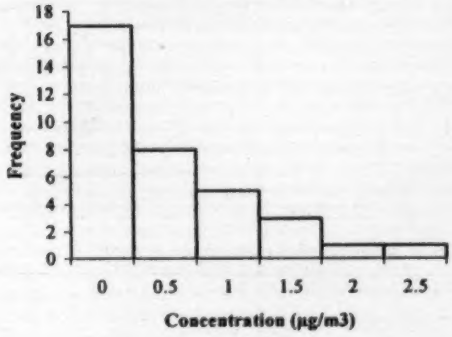
Frequency Histogram- Dec (Personal)



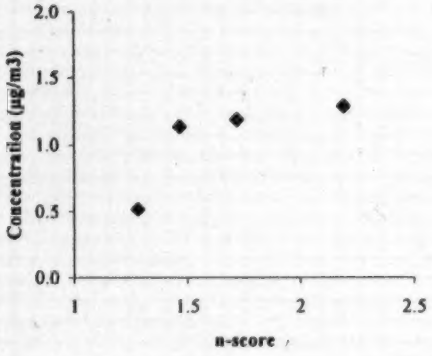
Normal Probability Plot- Meth (In)



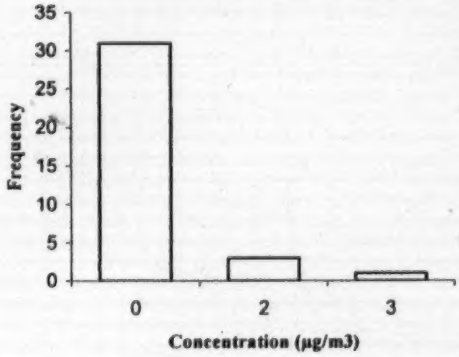
Frequency Histogram- Meth (In)



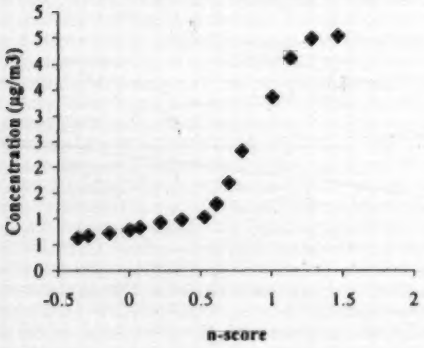
Normal Probability Plot- Meth (Out)



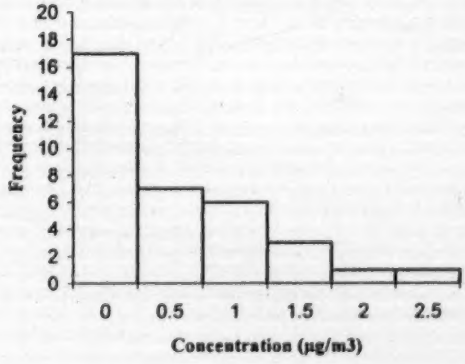
Frequency Histogram- Meth (Out)

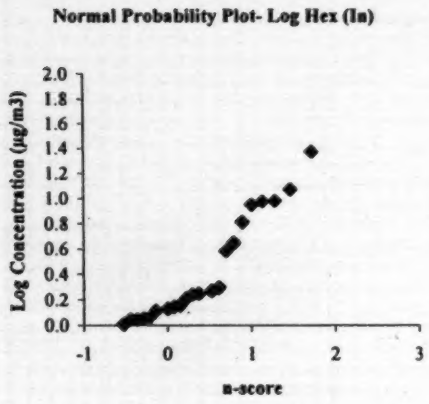


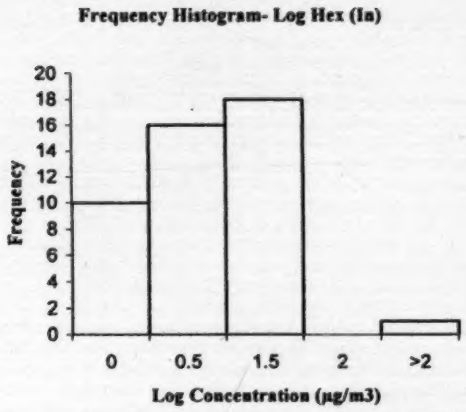
Normal Probability Plot- Meth (Personal)

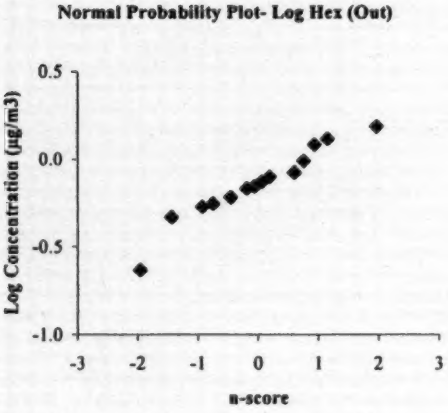


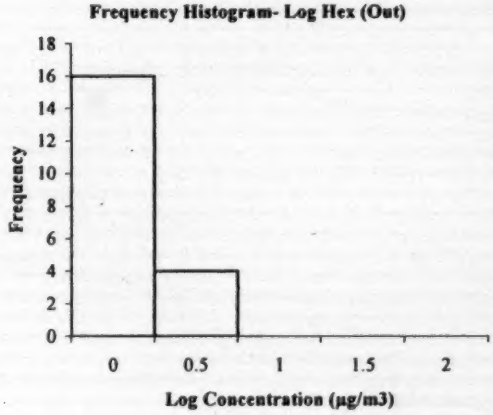
Frequency Histogram- Meth (Personal)

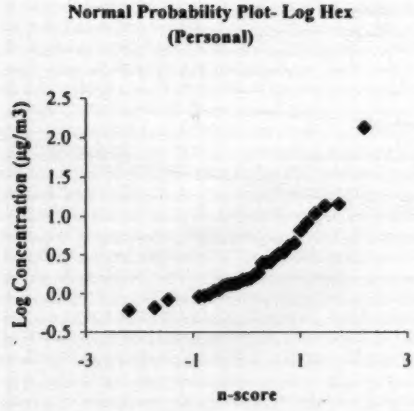


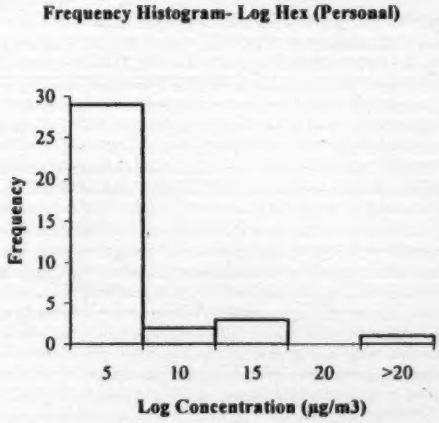

Normal Probability Plot- Log Hex (In)
Log Concentration (µg/m3)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-1
0
1
2
3
n-score


Frequency Histogram- Log Hex (In)
Frequency
20
18
16
14
12
10
8
6
4
2
0
0
0.5
1.5
2
>2
Log Concentration (µg/m3)

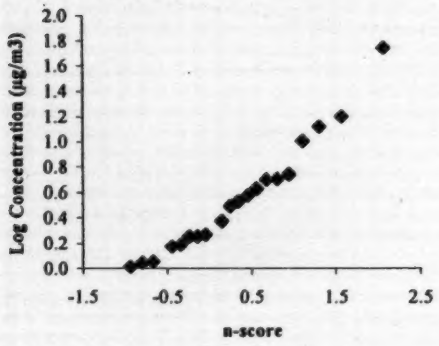

Normal Probability Plot- Log Hex (Out)
Log Concentration (µg/m3)
0.5
0.0
-0.5
-1.0
-3
-2
-1
0
1
2
3
n-score


Frequency Histogram- Log Hex (Out)
Frequency
18
16
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
Log Concentration (µg/m3)

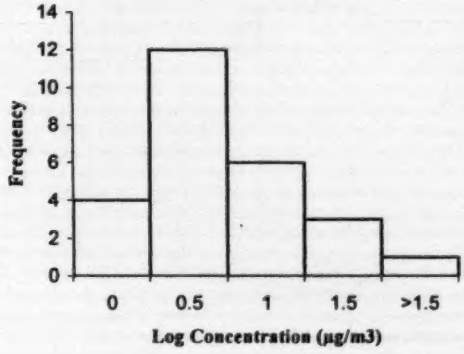

Normal Probability Plot- Log Hex
(Personal)
Log Concentration (µg/m3)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-3
-1
1
3
n-score


Frequency Histogram- Log Hex (Personal)
Frequency
30
25
20
15
10
5
0
5
10
15
20
>20
Log Concentration (µg/m3)

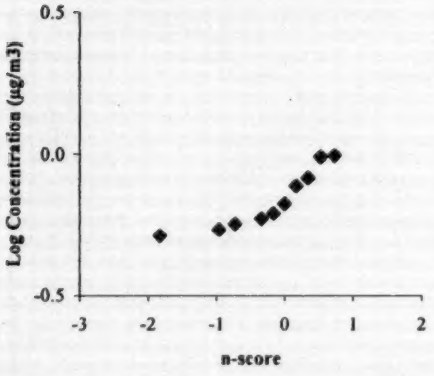
Normal Probability Plot- Log Hept (In)



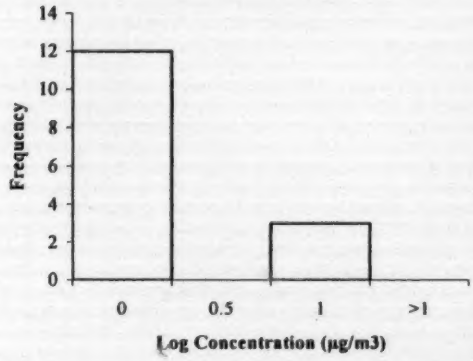
Frequency Histogram- Log Hept (In)



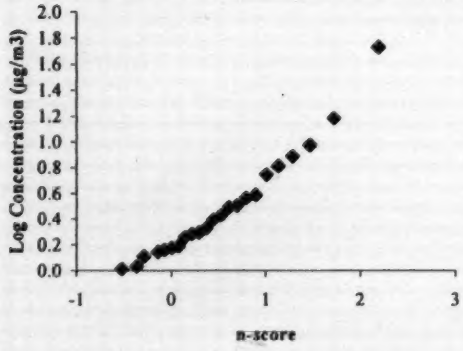
Normal Probability Plot- Log Hept (Out)



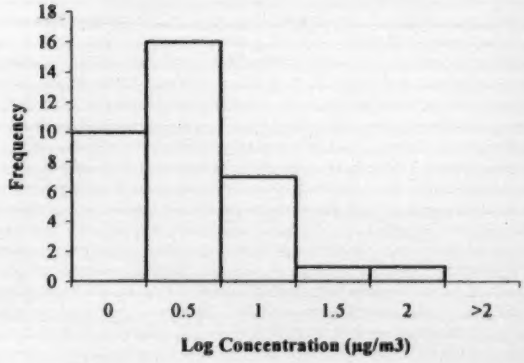
Frequency Histogram- Log Hept (Out)



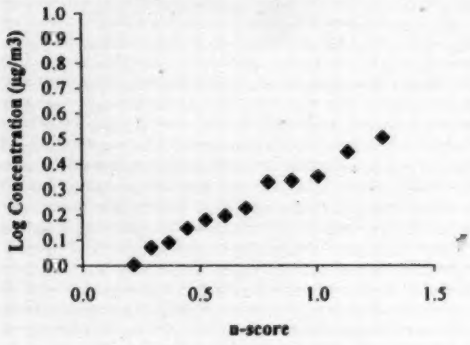
Normal Probability Plot- Log Hept (Personal)



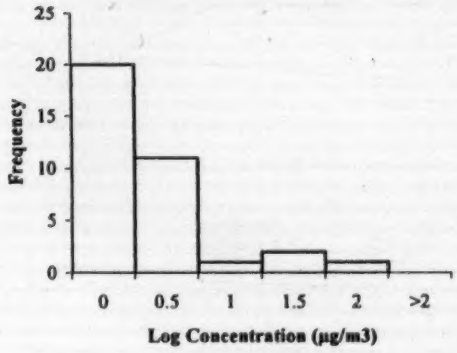
Frequency Histogram- Log Hept (Personal)



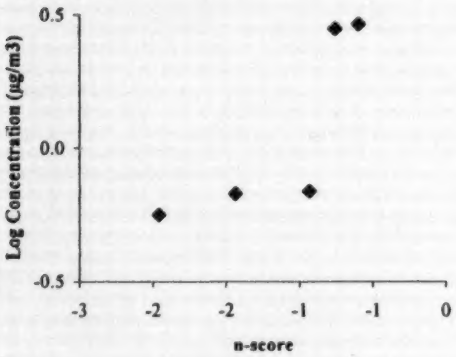
Normal Probability Plot- Log Oct (In)



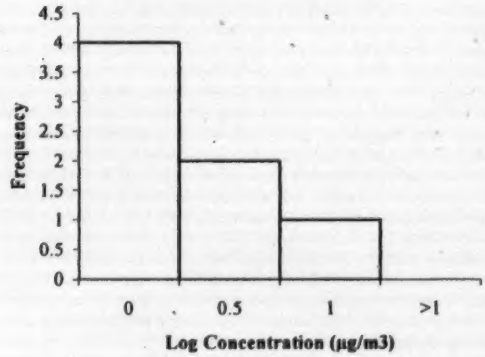
Frequency Histogram- Log Oct (In)



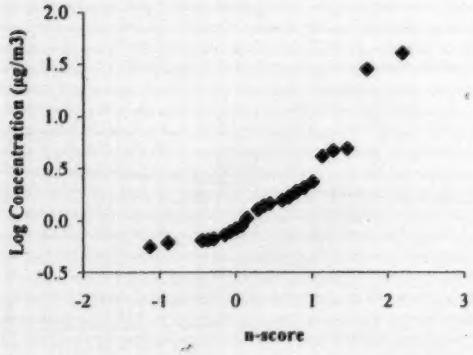
Normal Probability Plot- Log Oct (Out)



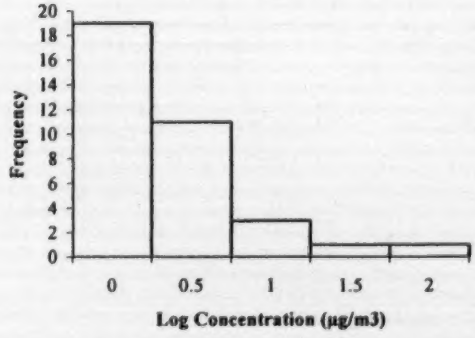
Frequency Histogram- Log Oct (Out)



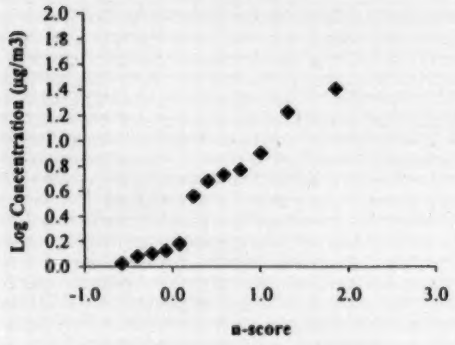
Normal Probability Plot- Log Oct (Personal)



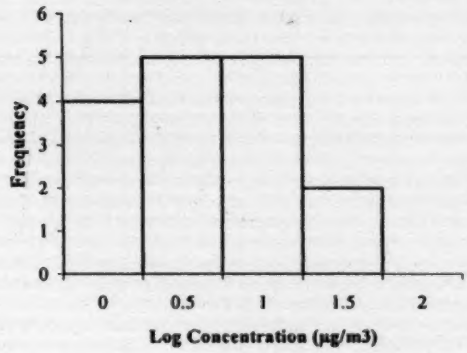
Frequency Histogram- Log Oct (Personal)



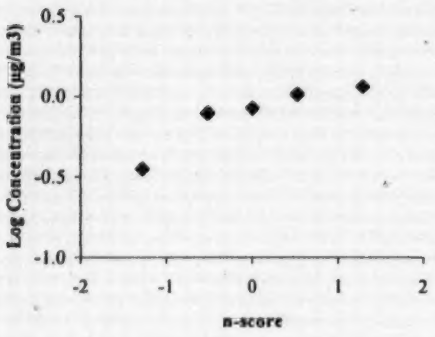
Normal Probability Plot- Log Non (In)



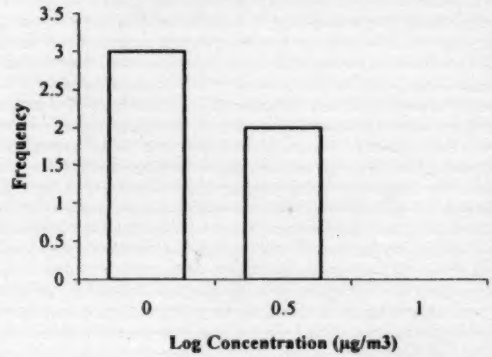
Frequency Histogram- LogNon (In)



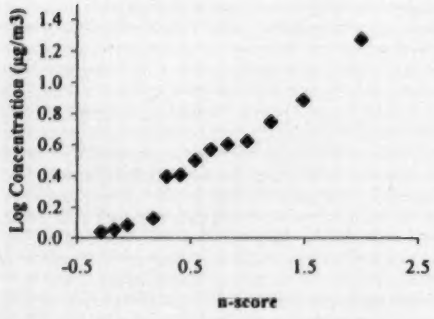
Normal Probability Plot- Log Non (Out)



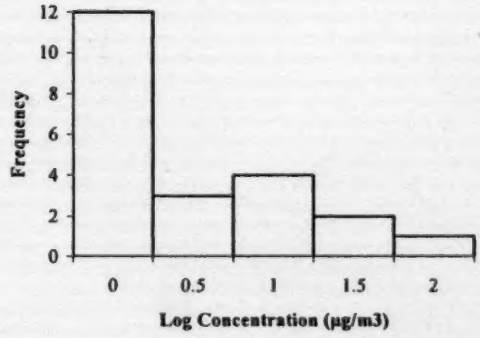
Frequency Histogram- Log Non (Out)

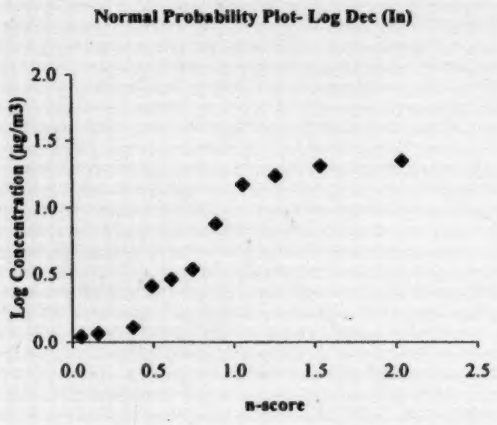


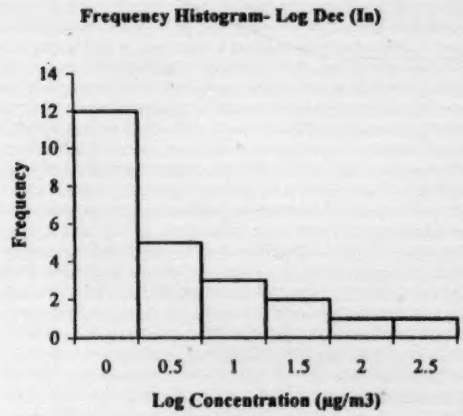
Normal Probability Plot- Log Non (Personal)

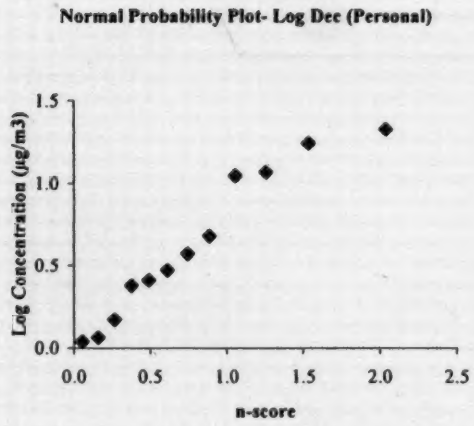


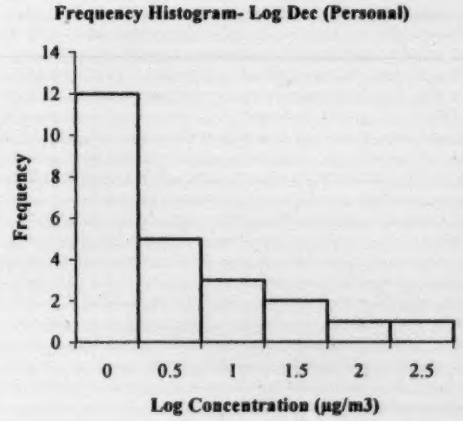
Frequency Histogram- Log Non (Personal)



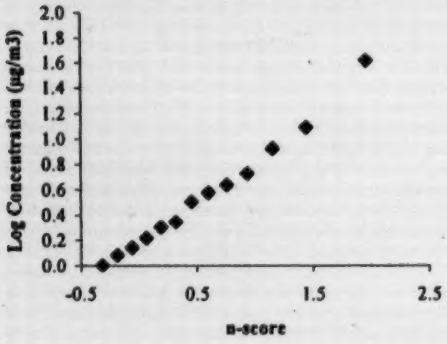

Normal Probability Plot- Log Dec (ln)
Log Concentration (µg/m3)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
n-score


Frequency Histogram- Log Dec (ln)
Frequency
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
Log Concentration (µg/m3)

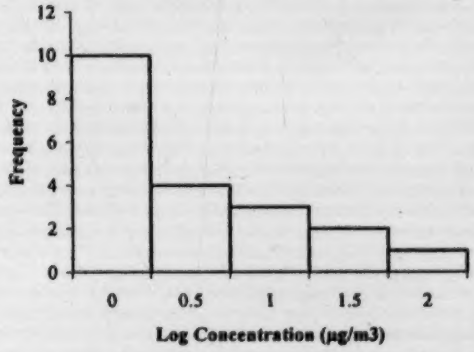

Normal Probability Plot- Log Dec (Personal)
Log Concentration (µg/m3)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
n-score


Frequency Histogram- Log Dec (Personal)
Frequency
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
Log Concentration (µg/m3)

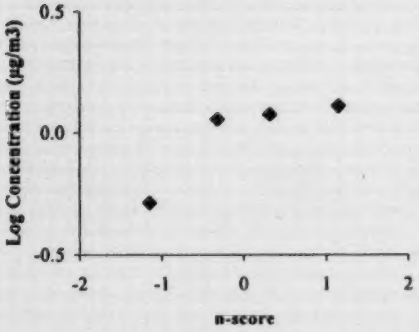
Normal Probability Plot- Log Meth (In)



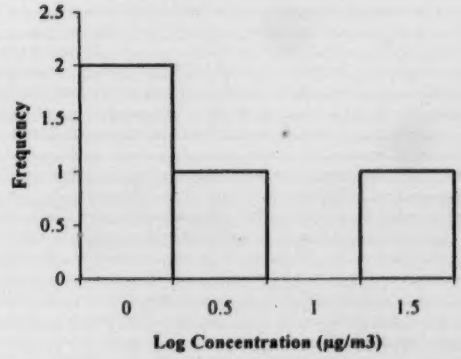
Frequency Histogram- Log Meth (In)



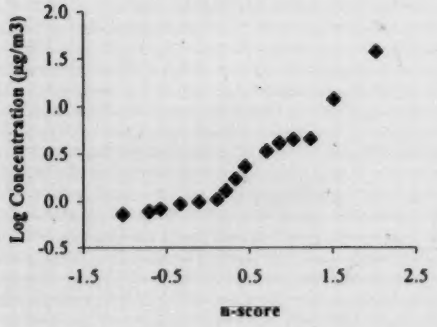
Normal Probability Plot- Log Meth (Out)



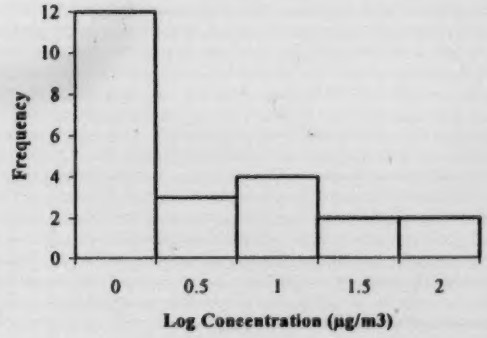
Frequency Histogram- Log Meth (Out)



Normal Probability Plot- Log Meth (Personal)



Frequency Histogram- Log Meth (Personal)



Terms:
Hex = Hexane
Hept = Heptane
Oct = Octane
Non = Nonane
Dec = Decane
Meth = 3-Methylhexane
In = Indoor
Out = Outdoor